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SEISMIC CRUSTAL AND SUBCRUSTAL PHASES PROPAGATION

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20. Abstract

Some thirteen earthquakes which occurred around or inside France generated local waves recorded on the French seismic network runned by L. D. G. up to 1 500 km. A rather qualitative study of these phases (Pn, Pg, Sn, Lg) was first conducted : phase identification, velocities computation, attenuation versus epicentral distance, comparison of the different quakes.

Pn and Sn waves are not very sensitive to superficial propagation anomalies and have attenuation factor around $\gamma = 2$ with $A \propto K D^{-\gamma}$ (D: distance). On the contrary Pg and Lg phases propagating through the crust are more sensitive to geological anomalies, and have consequently more dispersed attenuation factors.

For one of the thirteen earthquakes (off shore Brittany - 01.15.78) local phases have been studied in more details. By filtering process, the attenuation factor for each phase was computed versus distance from 0,5Hz to 16Hz.

For each local wave, high frequency amplitudes attenuate stronger than low frequency amplitudes, with distance. The maximum energy of Pn phases lies in the 8-16Hz band for distances below 400 km, and shifts to the 4-8Hz band for distances beyond 400 km.

Similarly Pg phases maxima shift from 4-8Hz to 2-4Hz for the same distance ranges. Lg maximum energy is found in the 0.5-4Hz band except for very short distances. In fact Lg attenuation factor versus distance increases with frequency, from 1.5 (0.5-1Hz) to 3.9 (8-16Hz).

On the other hand, the quality factor Q computed for each local phase also shows a clear increase with frequency. This first attempt to study in detail crustal and subcrustal waves is presently being extended to other earthquakes. We have already determined that Pg and Lg attenuate strongly when crossing particular tectonics features such as the "Sillon Rhodanien" in the South-East part of France and the Ivrea Zone in the Alps at the Italian border.

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SUMMARY

FIGURES CAPTION

A first examination of the records of 13 quakes recorded at short distances by the network aperated by the LDG (Fig. 1) (cf. our preliminary study) gave some attenuation factors for the local seismic phases, Pn, Pg, Sn, and Lg.

In table 1 we summary our results.

N : number of stations recording a peculier phase.

r : linear correlation coefficient of Log A versus Log D, (A : amplitude - D : distance)

γ : attenuation factor (Log A = γ Log D + C)

α : azimuth of the ray path.

The attenuation factor obtained so is a global one, valid for all the frequency band of our equipment (Vertical SP - 1 Cps - cut off at 20 Cps).

It gives very little information in the energy content of each phase versus frequency nor about the attenuation of the various frequencies.

A more detailled study is so needed which could be done through an analog or a digital system.

The analog equipment is older and not as versatile as the digital one, but gives a clear vision of the phenomenon. We so decide to use first our analog equipment to found the main parameters of the attenuation of local phases versus frequency for one peculiar quake.

In a later stage we will shift again to digital processing but, from the study we present here, it will be possible to decrease considerably the computation time.

TABLE I : Attenuation factor for broad band signals.

Quake	Δ	Pn			Pg			Sn			Lg		
		N	r	γ	N	r	γ	N	r	γ	N	r	γ
Cosne d'Allier	310	8	0,64	- 1,1	15	0,94	- 2,1				13	0,91	- 3,
St Pourcain / Sioule	310	10	0,13	+ 0,3	12	0,85	- 2,8				11	0,86	- 3,
Oleron	148	15	0,40	- 1,0	16	0,90	- 2,4	16	0,93	- 1,7		saturé	
Azimut S.E.	17	5	0,87	- 2,2	5	0,98	- 3,2	5	0,94	- 2,0		"	
Azimut N.E.	16	7	0,94	- 2,5	7	0,93	- 1,7	7	0,89	- 1,2		"	
Oviedo	52	18	0,75	- 3,0				18	0,68	- 2,5			
Azimut N.E.	14	12	0,73	- 2,9				12	0,74	- 3,2			
Oloron Ste Marie	83	16	0,35	- 0,7	12	0,92	- 3,8	13	0,80	- 2,2	13	0,88	- 3,
Azimut N.E	17	10	0,08	- 0,1	7	0,94	- 3,5	7	0,95	- 2,5	8	0,92	- 3,
Vallée d'Ossau	100	9	0,33	- 1,2	18	0,93	- 3,2	17	0,93	- 2,5	14	0,82	- 3,
Azimut N.E	21	4	0,61	-10,9	10	0,98	- 3,3	7	0,99	- 2,7	7	0,99	- 3,

Bologna	97	15	0,63	- 1,9	14	0,52	- 1,3	14	0,59	- 1,8	15	0,79	- 2,0
Azimut N.O	8	6	0,88	- 2,5	6	0,98	- 2,0	5	0,92	- 2,0	6	0,93	- 1,5
Azimut O	25	9	0,43	- 1,9				9	0,67	- 3,6			
Azimut O	12	8	0,77	- 3,5	8	0,31	- 1,3				8	0,62	- 2,4
Montenegro	35	15	0,89	- 5,2				15	0,76	- 3,5			
Udine	77	18	0,66	- 2,1	15	0,89	- 3,1	15	0,89	- 2,6	15	0,88	- 2,9
Azimut N.O	14	6	0,96	- 3,0	5	1,00	- 3,1	3	1,00	- 2,9	4	0,99	- 2,8
Azimut S.O.	16	8	0,76	- 3,1	7	0,87	- 4,3	8	0,77	- 3,4	8	0,65	- 4,2
Sigmaringen	73	15	0,70	- 1,3	17	0,92	- 2,2	19	0,92	- 2,1	15	0,83	- 2,0
Azimut O	27	8	0,86	- 1,5	8	0,96	- 2,0	9	0,95	- 1,9	6	0,96	- 1,8
Azimut S.O.	28	7	0,90	- 2,2	9	0,96	- 3,0	10	0,98	- 2,6	8	0,93	- 2,7
Mons	112	16	0,26	+ 0,7	16	0,85	- 2,5	15	0,60	- 1,3	14	0,84	- 2,1
Azimut S	22	9	0,18	+ 0,3	9	0,88	- 1,9	9	0,93	- 1,7	8	0,90	- 2,0
Offshore Britanny	55	17	0,87	- 1,9	17	0,95	- 3,0	17	0,85	- 2,1	17	0,91	- 2,6
Azimut E	18	11	0,88	- 1,9	11	0,96	- 3,0	11	0,95	- 2,2	11	0,95	- 2,8
Aix la Chapelle	85	11	0,08	+ 0,3	12	0,75	- 1,1	14	0,46	- 1,1	16	0,88	- 2,2
Azimut S	14	6	0,73	- 3,6	7	0,64	- 1,1	7	0,36	- 0,6	9	0,89	- 2,5

TABLE I (continue)

QUAKES LOCALISATION

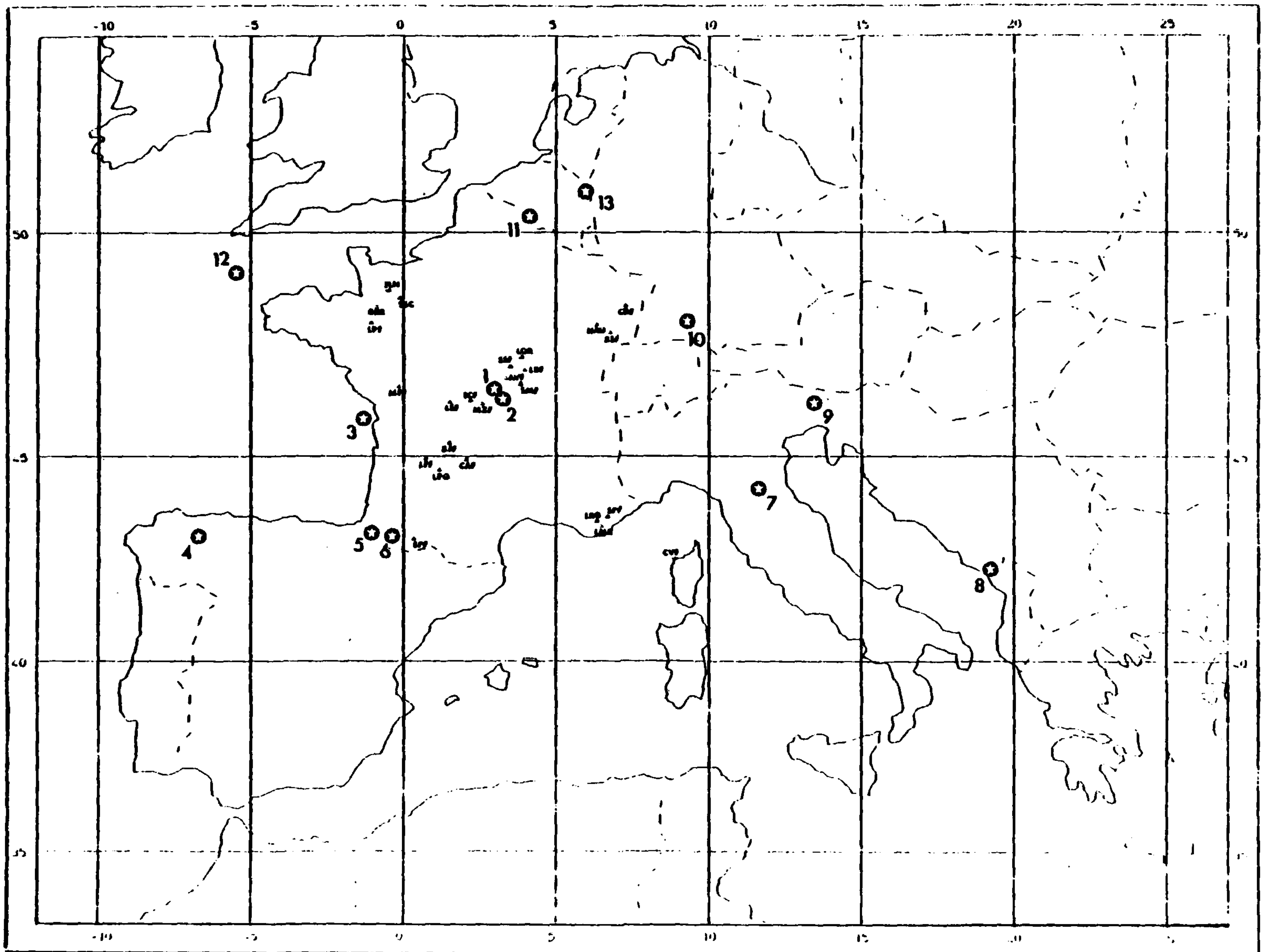


Fig. 1

Selection of the quake to be processed.

Among the 13 quakes, we studied, we select one, off shore of Britanny (n 12 of the preliminary report). to test the analog process of the data.

The epicenter of this quake (49. 09 N - 5. 49 W) is some hundred kilometers from the west shore of France.

The quake was well recorded on 20 stations, the minimum distance beeing 349km and the maximum one 1105km.

The different phases are distinct and there is no obvious geological barrier to the propagation (Fig. 2).

Description of the process.

We first divide the band pass of our record into five parts :

0, 5 - 1, 0 Hz
1. 0 - 2. 0 Hz
2. 0 - 4. 0 Hz
4. 0 - 8. 0 Hz
8. 0 - 16. 0 Hz

Higher frequencies have no meaning (cut off of the transmission line due to a digitalisation at 50cps) and lower frequencies few meaning (seismometer at 1 cps).

The filters are ajustable Butterworth with slope of 24 dB/o on each side.

We apply each filter to the entire signal and plot :

- the filtered signal.

- the envelope of the filtered signal (with an integration constant of 6 sec.).

- the unfiltered signal with same magnification as the filtered one.

- the envelope of the unfiltered signal.

Results

We studied the filtered signal in two way :

- qualitatively, by group of stations at nearly the same distance and in similar geology situation.

- quantitatively, to obtain the attenuation factors .

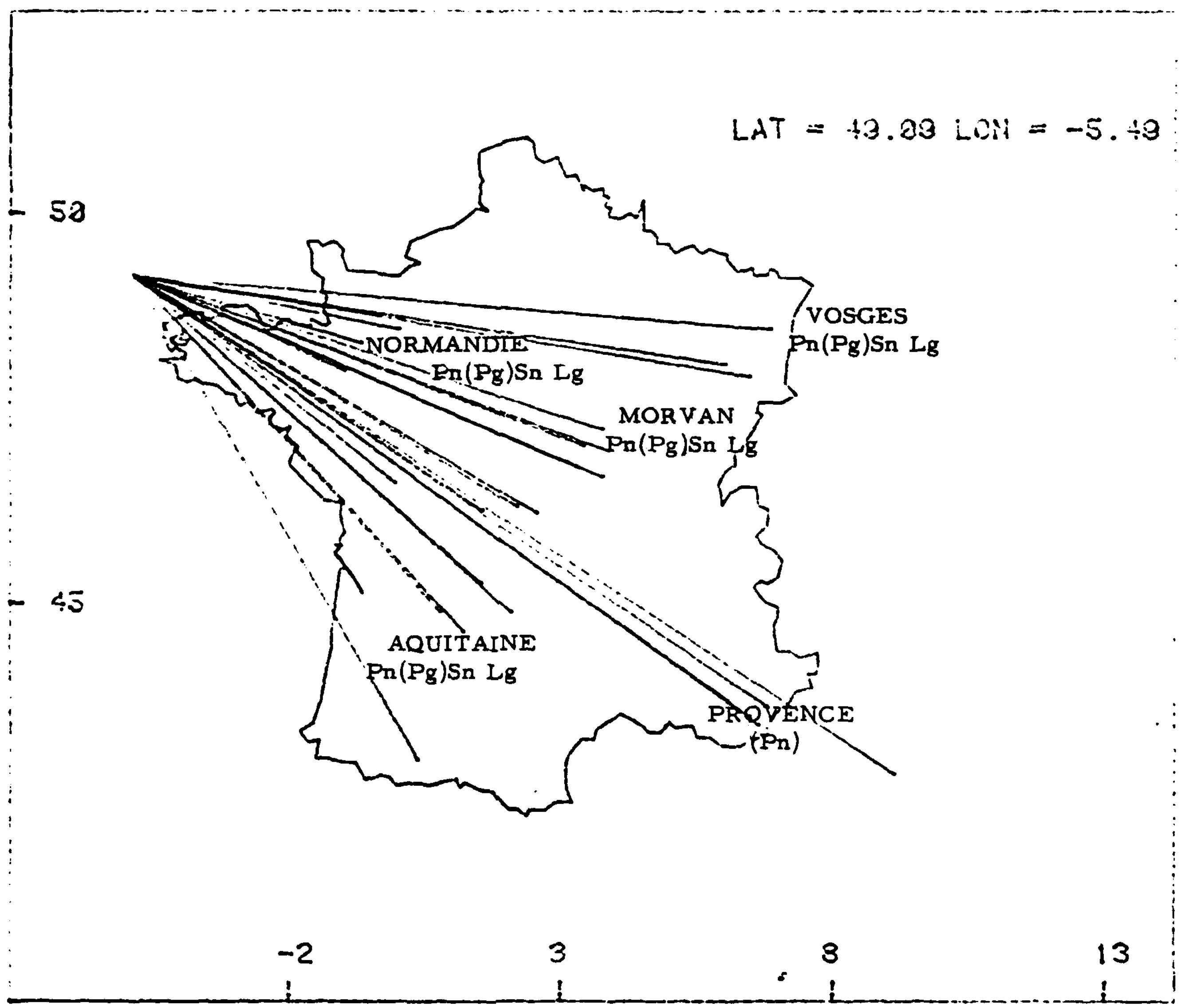

LAT = 49.00 LON = -5.49
50
45
-2
3
8
13
VOSGES
Pn(Pg)Sn Lg
NORMANDIE
Pn(Pg)Sn Lg
MORVAN
Pn(Pg)Sn Lg
AQUITAINE
Pn(Pg)Sn Lg
PROVENCE
(Pn)

Fig. 2

Qualitative observation of signals

1) Normandy Stations (West of France). Distances from 349 to 398Km.

a)) unfiltered signal = the 4 seismic phases are recorded, but not equally well.

Pn is the first arrival - impetus

Pg arrival is small - emergence

The total duration is about 2mn.

b)) filtered signals

0.5 - 1Hz : only Lg is clear. No Pn at all, very small Pg and Sn.

For Lg, higher frequencies arrive first, then lower frequencies. The maximum of energy is at 0.8 - 0.9Hz. (Fig. 3)

1.0 - 2Hz : no Pn - clearer arrivals of Pg and Sn; Lg is still the largest phase with it maximum for 1.25 to 1.70Hz;

The maximum energy for Sn at 1.6Hz and for Pg at 2Hz.

The decrease in energy for Lg is very pronounced between GRR (349km) and FLN (368km) (of the order of 70%) but small between FLN and SSC(398Km

We still observe a dispersion of Lg phase, higher frequencies first. (Fig. 4)

2 - 4Hz :Pn small but possible to be seen. For Pg at SSC the energy in that ba is of the order of the energy of the unfiltered signal. The energy of Sn in the same band is also a noticable portion of the total energy. (Fig. 5)

4 - 8Hz : Pn is clear. Lg strongly attenuated.

The energies of Pg and Sn are large in FLN and GRR, but small in the third station of SSC. (Fig. 6)

8 - 16Hz : no Lg any more at SSC, very small at FLN and GRR. Pg is also strongly attenuated, but Pn and Sn are still strong. (Fig. 7)

2) Aquitaine Stations (South-West of France), distances from 660Km to 676Km.

a)) unfiltered signal. Pn, first arrival, Sn and Lg present good arrivals. The arrivals of Pg are more questionnable. Amplitude of Sn is large compared to Pn and Pg. Lg has the largest amplitude.

The total duration is about 3mn.

b)) filtered signal :

<u>O. 5 - 1Hz</u> : Lg well recorded, maximum energy at 1Hz. The maximum of Sn is at 0. 8Hz.

<u>1 - 2Hz</u> : Lg is still the largest wave but the others are also clear and specially Sn. Arrival times are better than in the infiltered signal (Only Pg arrival is not good). 70% of the energy content of Lg is in this band.

<u>2 - 4Hz</u> : Lg still large but the others phases are larger.

<u>4 - 8Hz</u> : Decrease of Lg amplitude Sn and Pn are the larger phases. Pg is not very clear.

<u>8 - 16Hz</u> : No Lg any more and practically no Pg either.

3) <u>Morvan Stations</u> (Center of France), distances from 706 to 748Km.

a)) infiltered signal : only 3 phases ; Pn, Sn and Lg. amplitude of Sn larger than Lg in 2 of the 5 stations (AVF and SMF) of similar value in the 3 others (SSF, LOR and LBF). Total duration 3. 5 minutes.

b)) filtered signal.

<u>0. 5 - 1Hz</u> : very small amplitude in general. Lg has its maximum energy at 0. 8 to 1Hz. no Pn.

<u>1 - 2Hz</u> : all phases are possible to be read but small amplitude specially for Pg.

<u>2 - 4Hz</u> : decrease of Lg in all stations, but the energy of Pn and Sn is increased. No clear separation between Pn , Pg and Sn, Lg .

<u>4 - 8Hz</u> : Pn and Sn are clear. Pg is not good, Lg disappear in nearly all stations.

<u>8 - 16Hz</u> : Only Pn and Sn but with a small energy.

4) <u>Vosges Stations</u> (North East of France), distances from 881 to 940Km

<u>Unfiltered signal</u> : The 4 phases are possible to identify. Pn and Sn arrivals are good , but Pg and Lg arrivals poor.

In the station (HAU) the maximum amplitude of Lg is of the same order of magnitude as the maximum amplitude of Sn.

In the two other Stations (BSF, CDF) it is some what larger. The duration of the signal is about 4mn.

Filtered signal :

0. 50 - 1Hz : no Pn - Maximum energy of Pg à 1Hz. Sn is small and has its maximum on the side of the band at 1. 1Hz. Lg is the best phase with its maximum àt 1Hz.

1 - 2Hz : large amplitude for Lg. The energy of Sn is also important. Pg is still very small and Pn is now possible to read.

2 - 4Hz : in HAU, the amplitude of Lg is larger then in the 1 - 2Hz band, but in the 2 other Stations (CDF and BSF) smaller. The 3 other phases increased in amplitude in all 3 Stations. Pn is nevertheless still small.

4 - 8Hz : strong attenuation of Lg in all Stations as for Pg small attenuation for Pn and Sn.

8 - 16Hz : Pn and Sn are the only phases possible to read but small.

5) Provence Station : (South East of France), distance 1105Km.

Unfiltered signal : no signal.

Filtered signal : only in the Station of LRG a small signal is possible to extract from the tape.

0. 5 - 1Hz and 1 - 2Hz : no signal.

2 - 4Hz : small Pn.

4 - 8Hz : Pn not very large but has its maximum in this band.

8 - 16Hz : small Pn.

Attenuation factor.

For each frequency band, we studied attenuation factor in the same way as was done in the preliminary report for the infiltered signal.

The amplitude A of the signal is represented versus distance D by a law:

$$A = C \times D^{\gamma}$$

We computed the attenuation factor γ and the value of the correlation coeficient r between Log A and Log D.

The computation was done both on the maximum amplitude of the filtered signals and on their envelope with the some résults.

The results are given in the next part, and in the part IV we will also give the Q factor for various phases and frequencies.

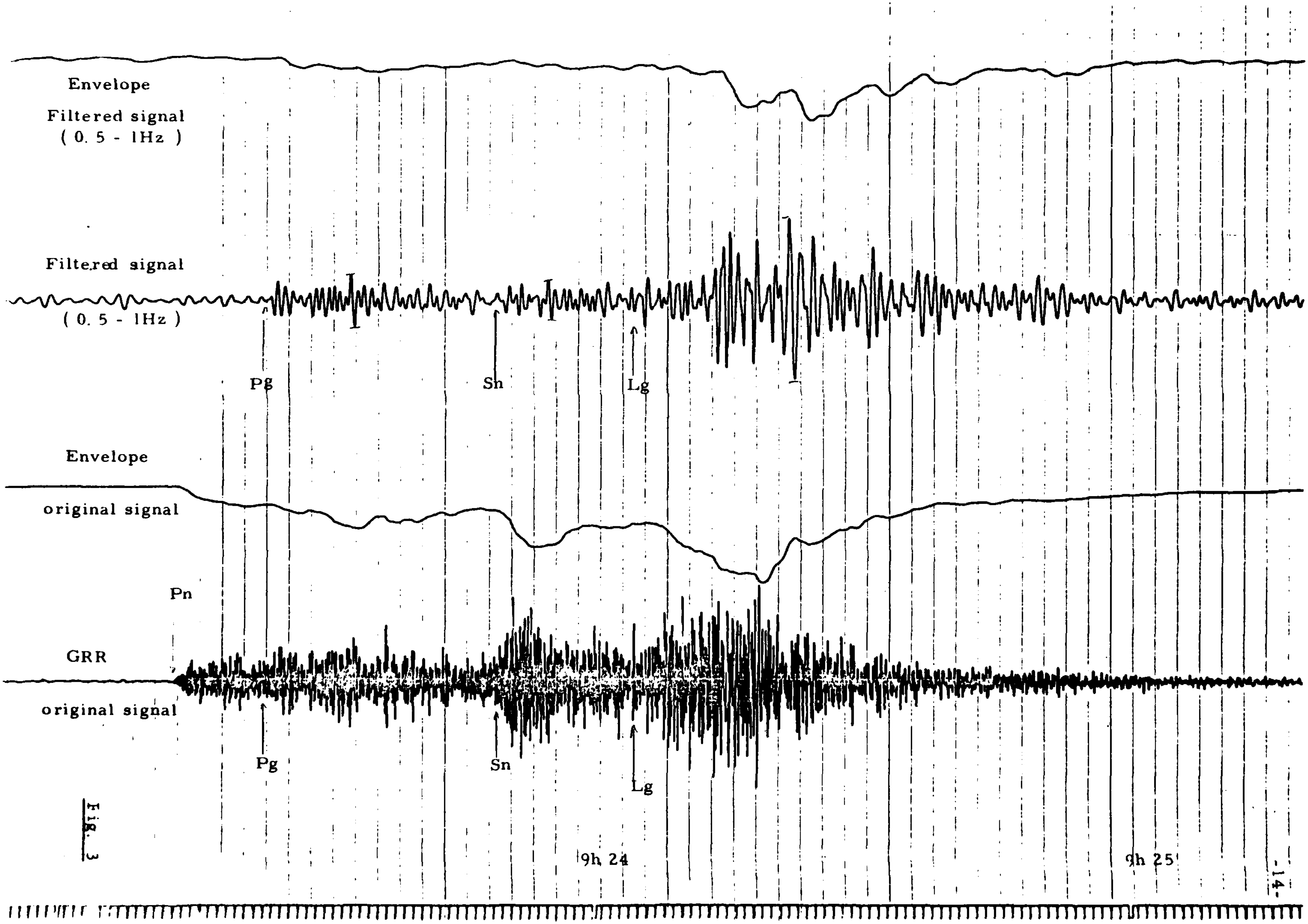

Envelope
Filtered signal
(0. 5 - 1Hz)
Filtered signal
(0. 5 - 1Hz)
Pg
Sn
Lg
Envelope
original signal
Pn
GRR
original signal
Pg
Sn
Lg
9h 24
9h 25

Fig. 3

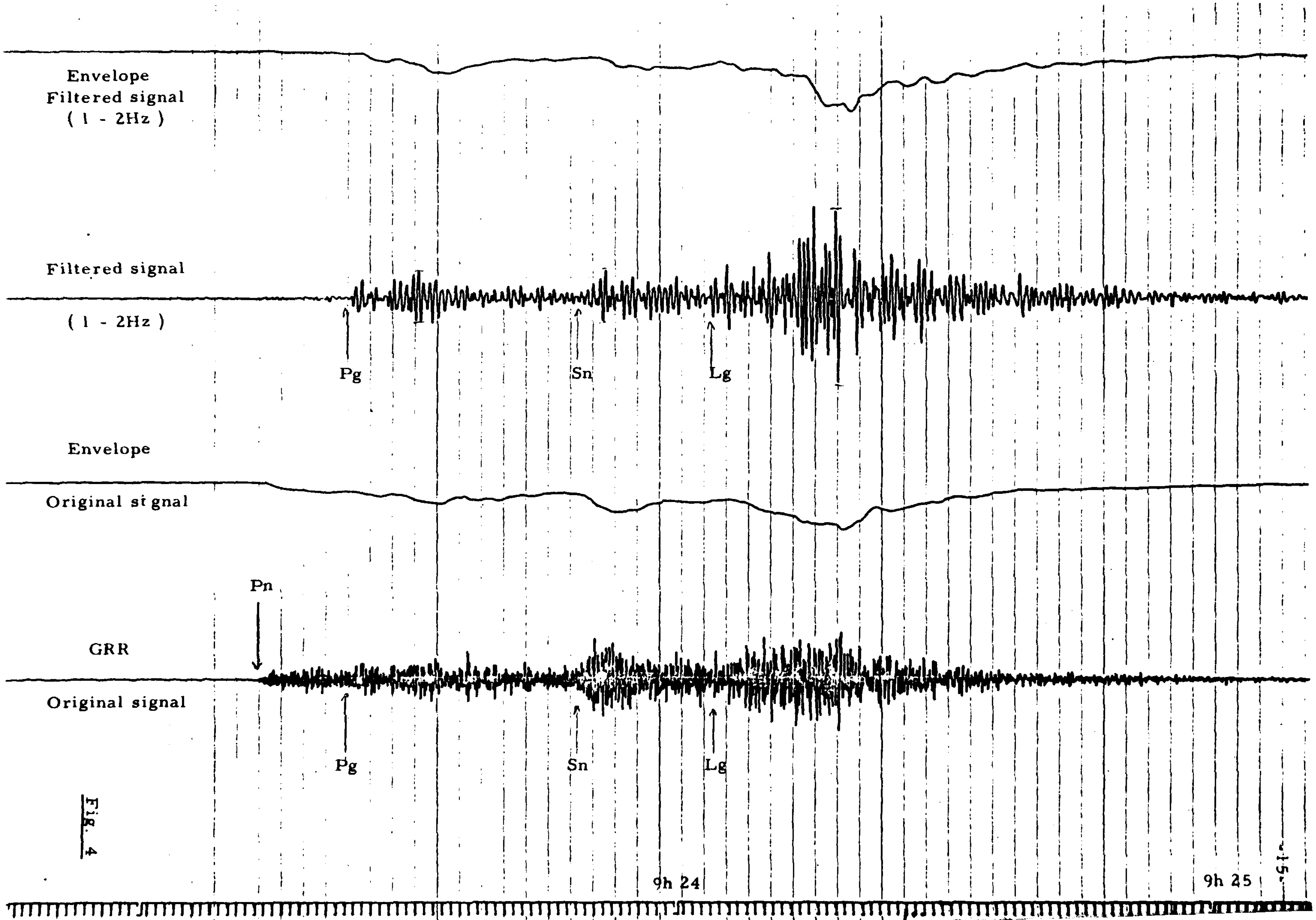

Envelope
Filtered signal
(1 - 2Hz)
Filtered signal
(1 - 2Hz)
Pg
Sn
Lg
Envelope
Original signal
Pn
GRR
Original signal
Pg
Sn
Lg
9h 24
9h 25

Fig. 4

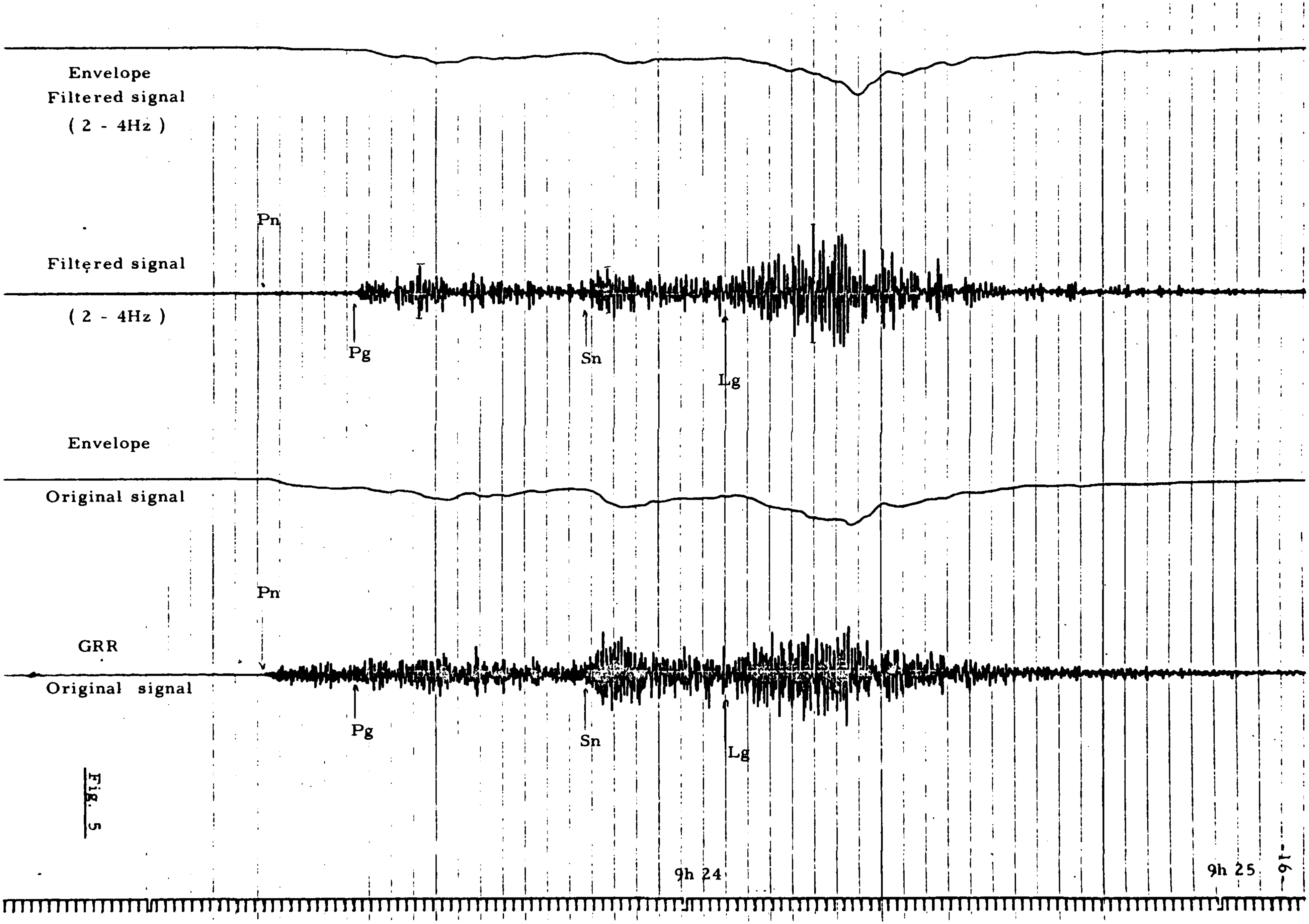

Envelope
Filtered signal
(2 - 4Hz)
Pn
Filtered signal
(2 - 4Hz)
Pg
Sn
Lg
Envelope
Original signal
Pn
GRR
Original signal
Pg
Sn
Lg
9h 24
9h 25

Fig. 5

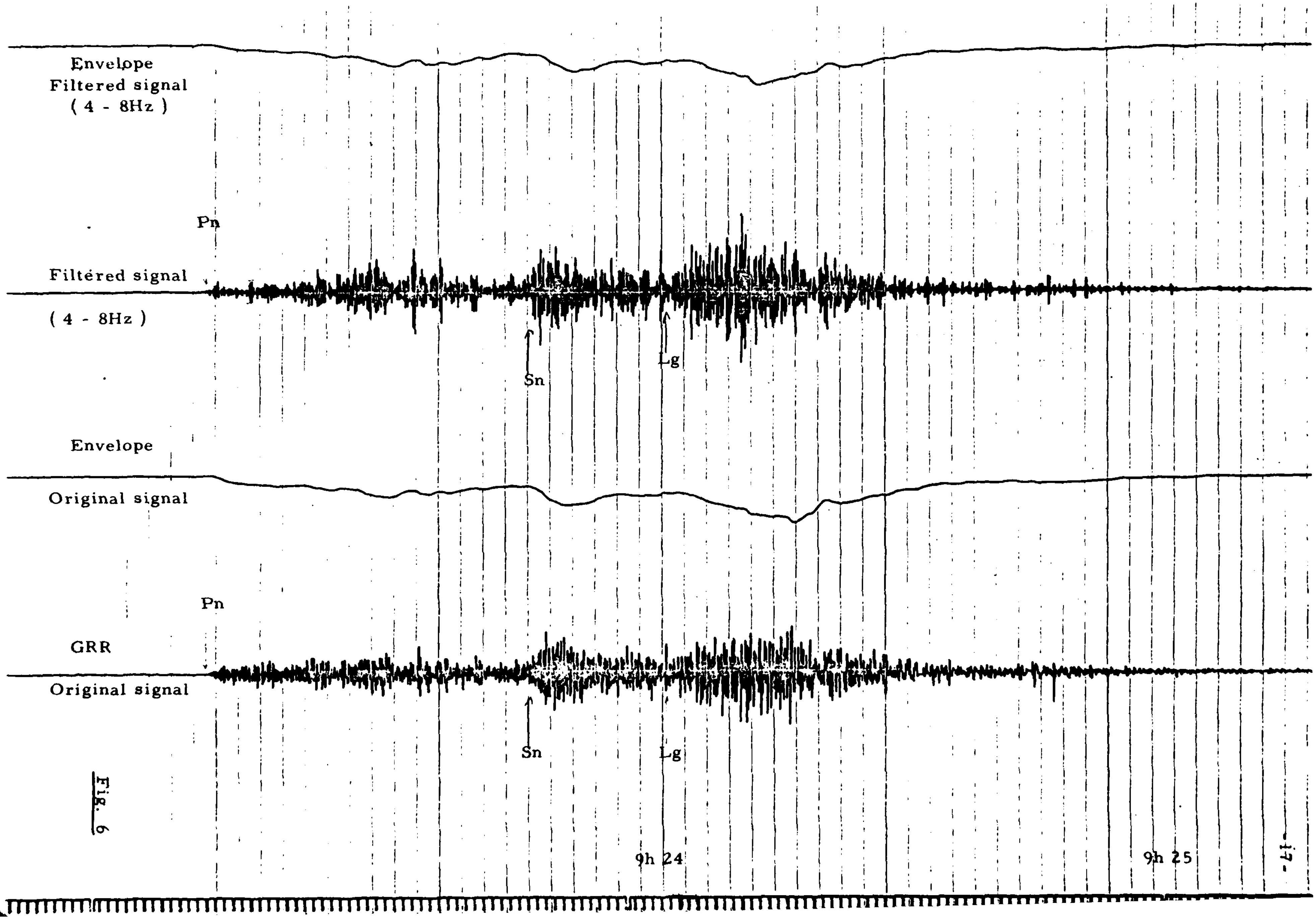

Envelope
Filtered signal
(4 - 8Hz)
Pn
Filtered signal
(4 - 8Hz)
Sn
Lg
Envelope
Original signal
Pn
GRR
Original signal
Sn
Lg
9h 24
9h 25

Fig. 6

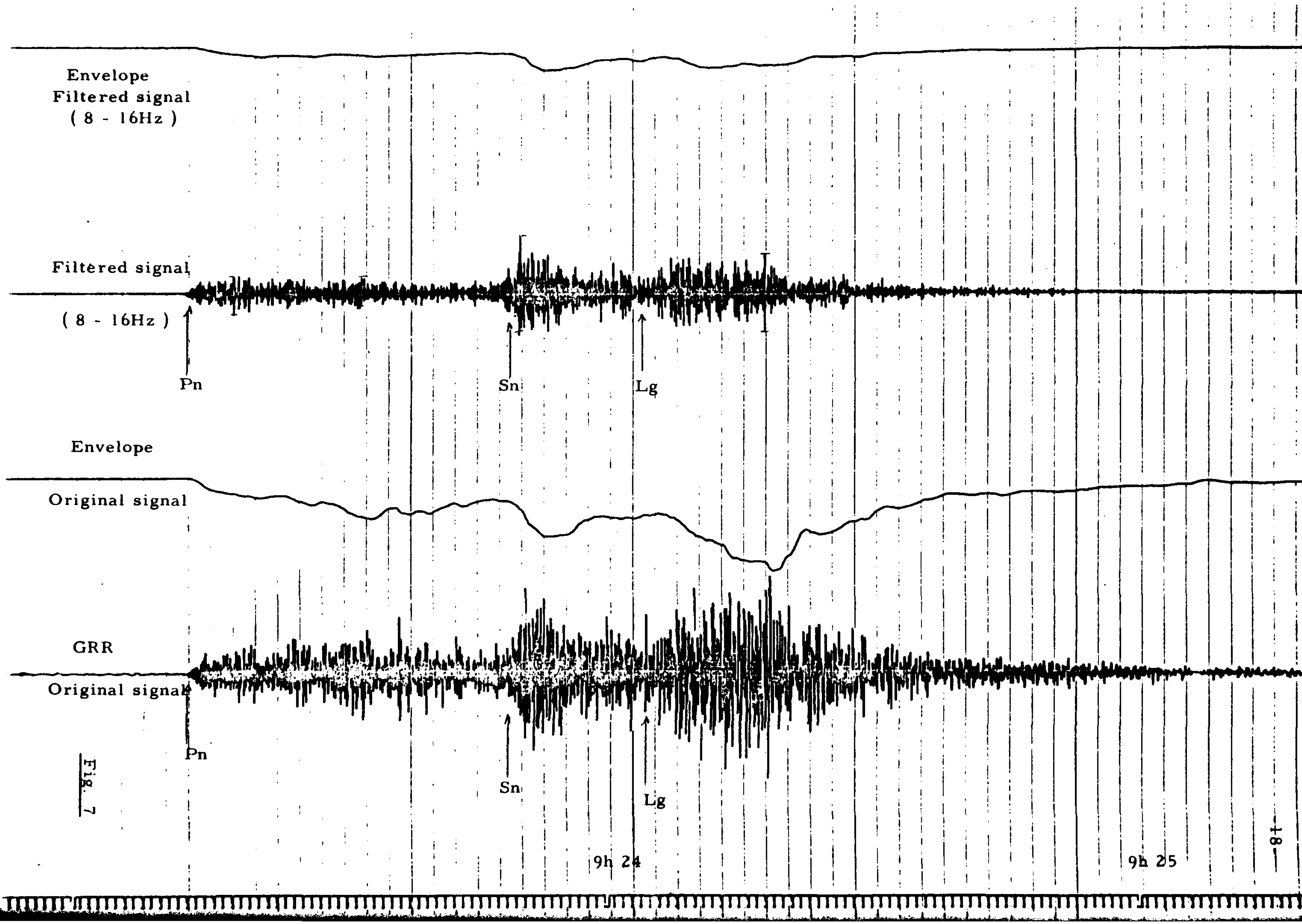

Envelope
Filtered signal
(8 - 16Hz)
Filtered signal
(8 - 16Hz)
Pn
Sn
Lg
Envelope
Original signal
GRR
Original signal
Pn
Sn
Lg
9h 24
9h 25

Fig. 7

In this third part will be found :

- a table which summaries all results obtained for attenuation factors γ for each phase and each frequency band as wellas the correlation coefficients r.

Then for each phase :

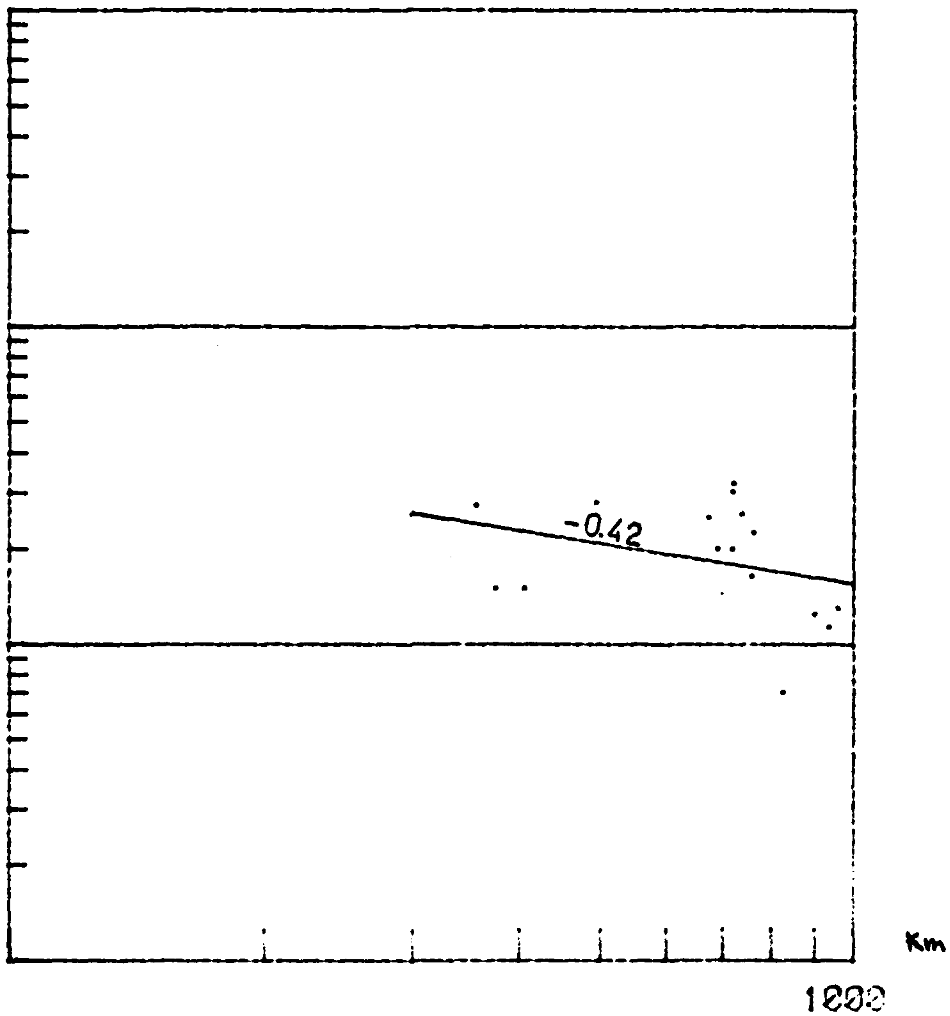
- A plot of the amplitude versus distance in each frequency band.
- The spectra of the waves for several distances.
- A summary of the main results.

TABLE II : Table of attenuation factor

frequency band	Pn			Pg			Sn			Lg		
	N	γ	r	N	γ	r	N	γ	r	N	γ	r
0.5-1Hz				8	-1.90	0.93	15	-1.00	0.88	16	-1.54	0.86
1 -2Hz	16	-0.42	0.31	16	-2.26	0.86	16	-1.60	0.84	16	-2.21	0.89
2 4Hz	17	-1.22	0.77	16	-3.05	0.96	16	-1.81	0.85	16	-2.77	0.91
4 -8Hz	17	-1.76	0.81	16	-3.59	0.96	16	-1.82	0.79	16	-3.89	0.95
8 -16Hz	17	-2.69	0.87	13	-3.55	0.92	16	-2.32	0.80	5	-3.90	0.91
unfiltered signal	17	-1.92	0.87	17	-2.96	0.95	17	-2.08	0.85	17	-2.62	0.91

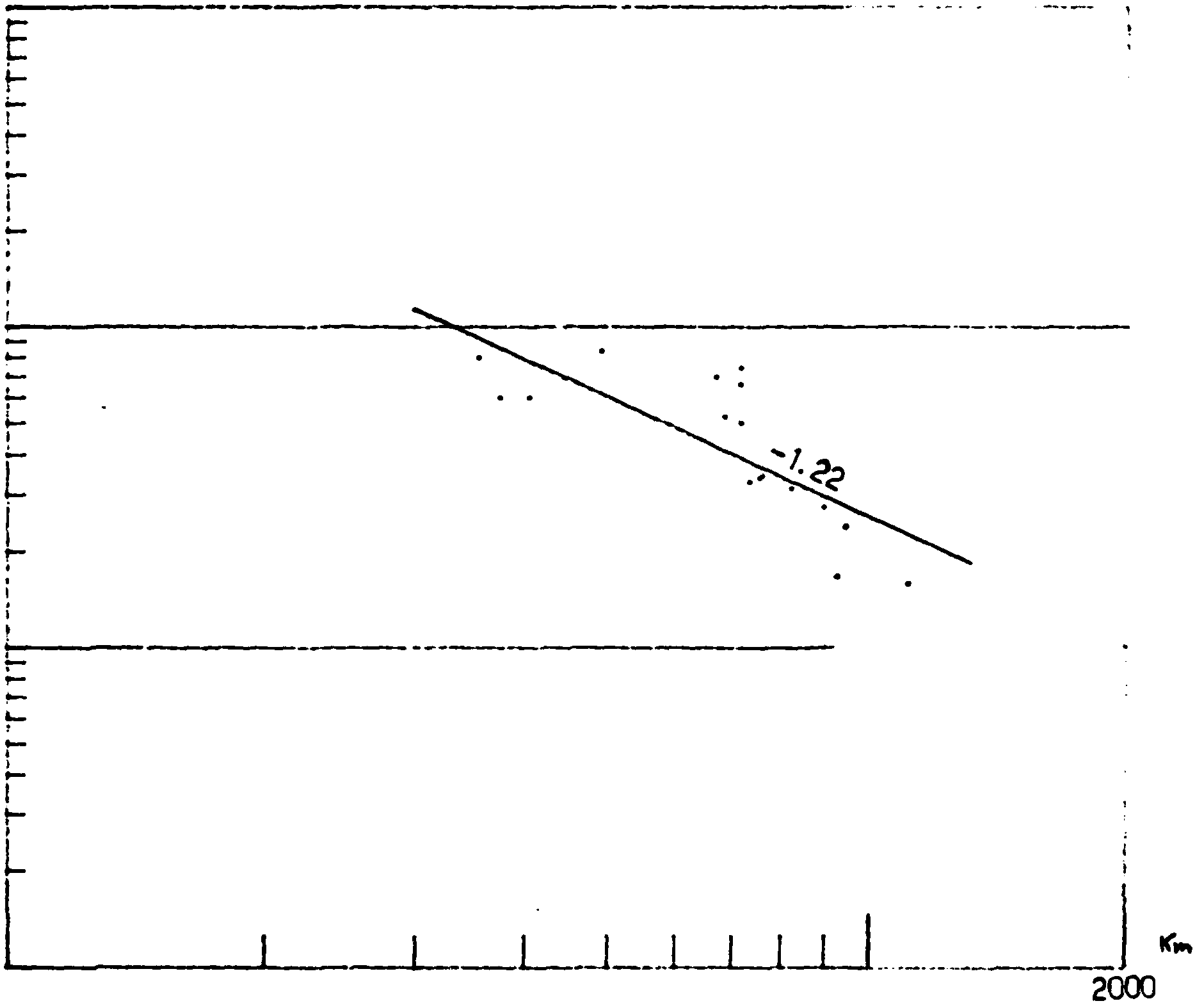
Pn Phase

- Plot of Amplitude versus distance.
- Spectra at various distances
- Main characteristics.



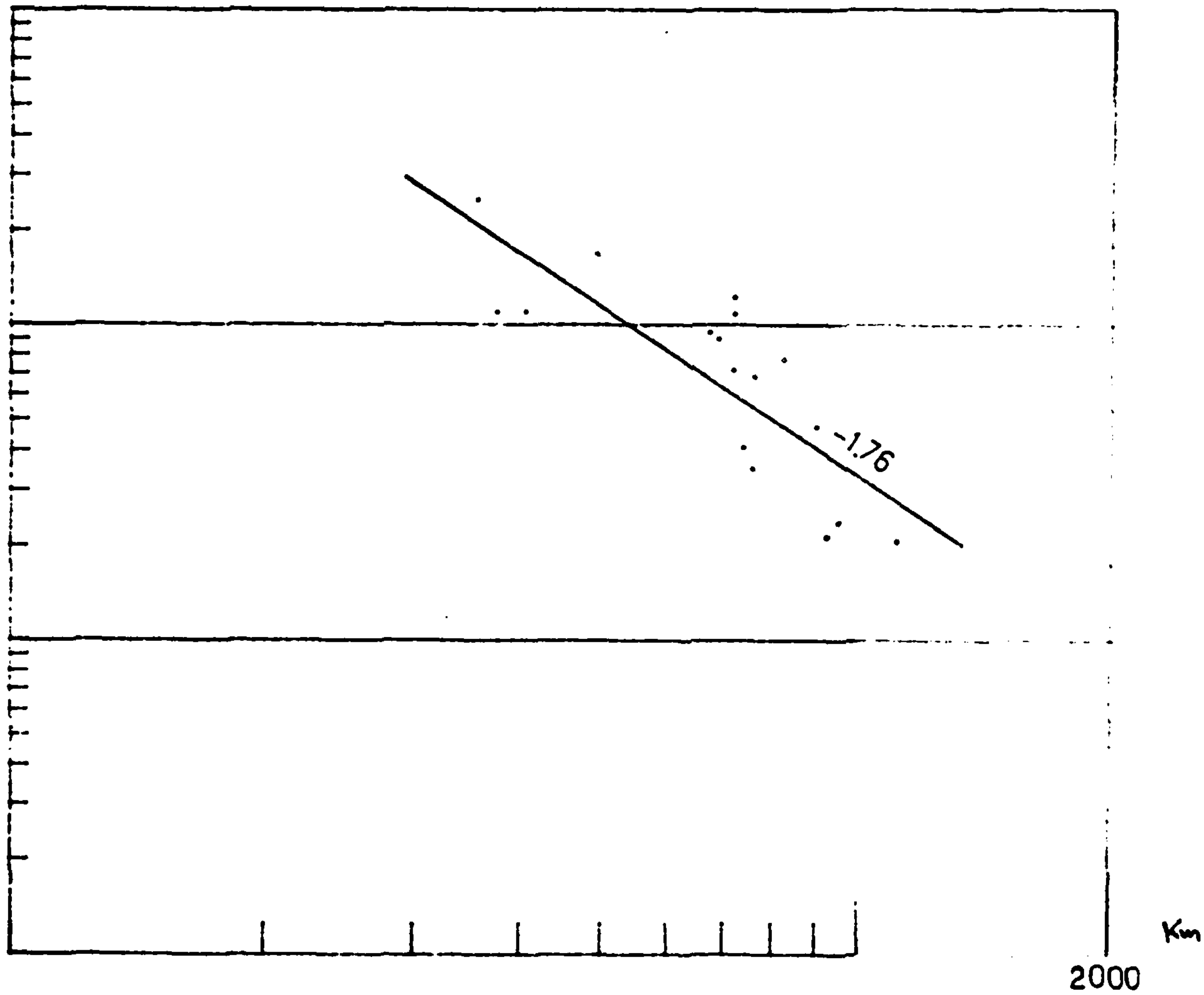
QUAKE 12.ATTENUATION Pn PHASE
FILTERED SIGNAL:1 - 2 Hz

Fig. 8



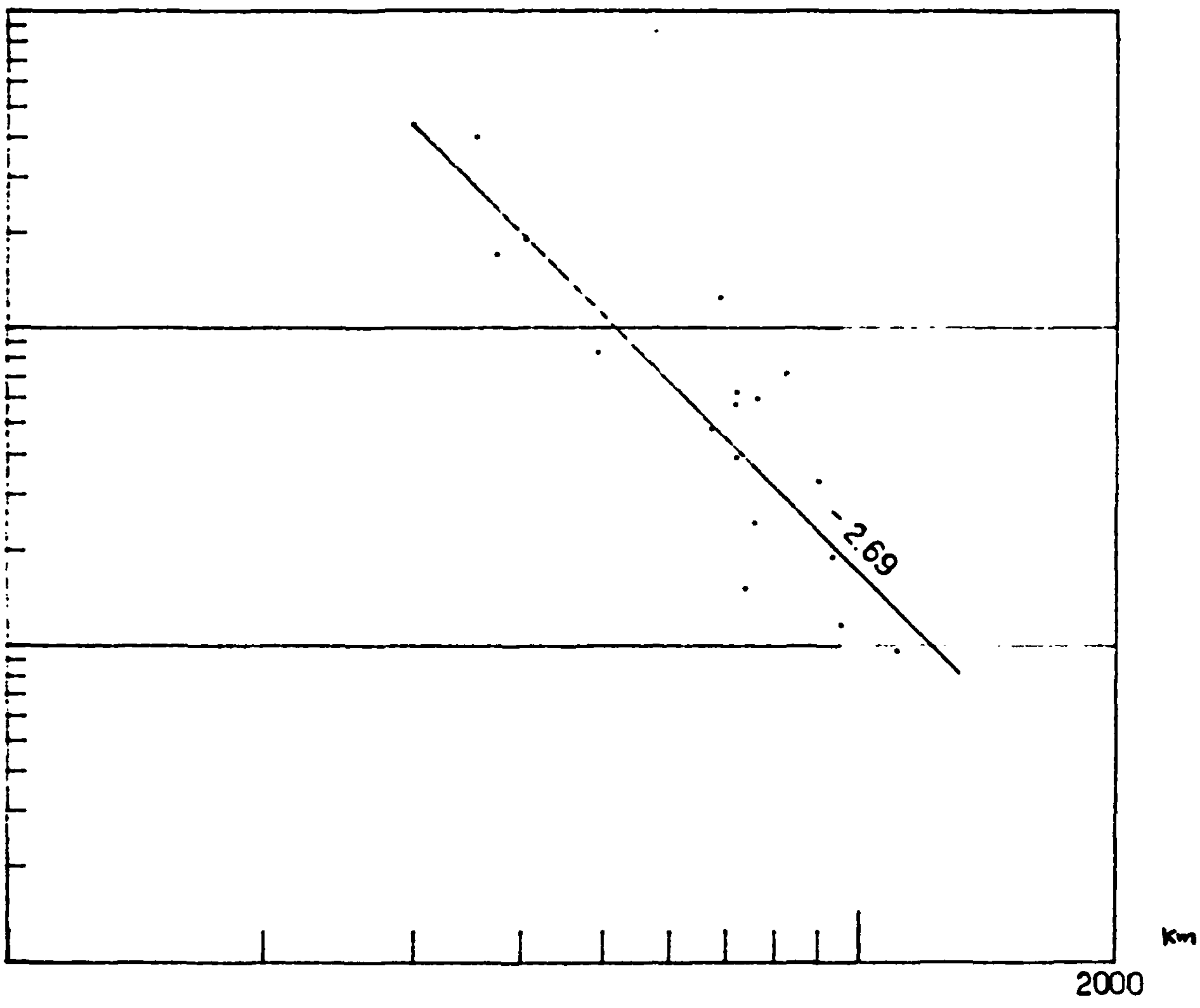
QUAKE 12.ATTENUATION Pn PHASE
FILTERED SIGNAL:2 - 4 Hz

Fig. 9



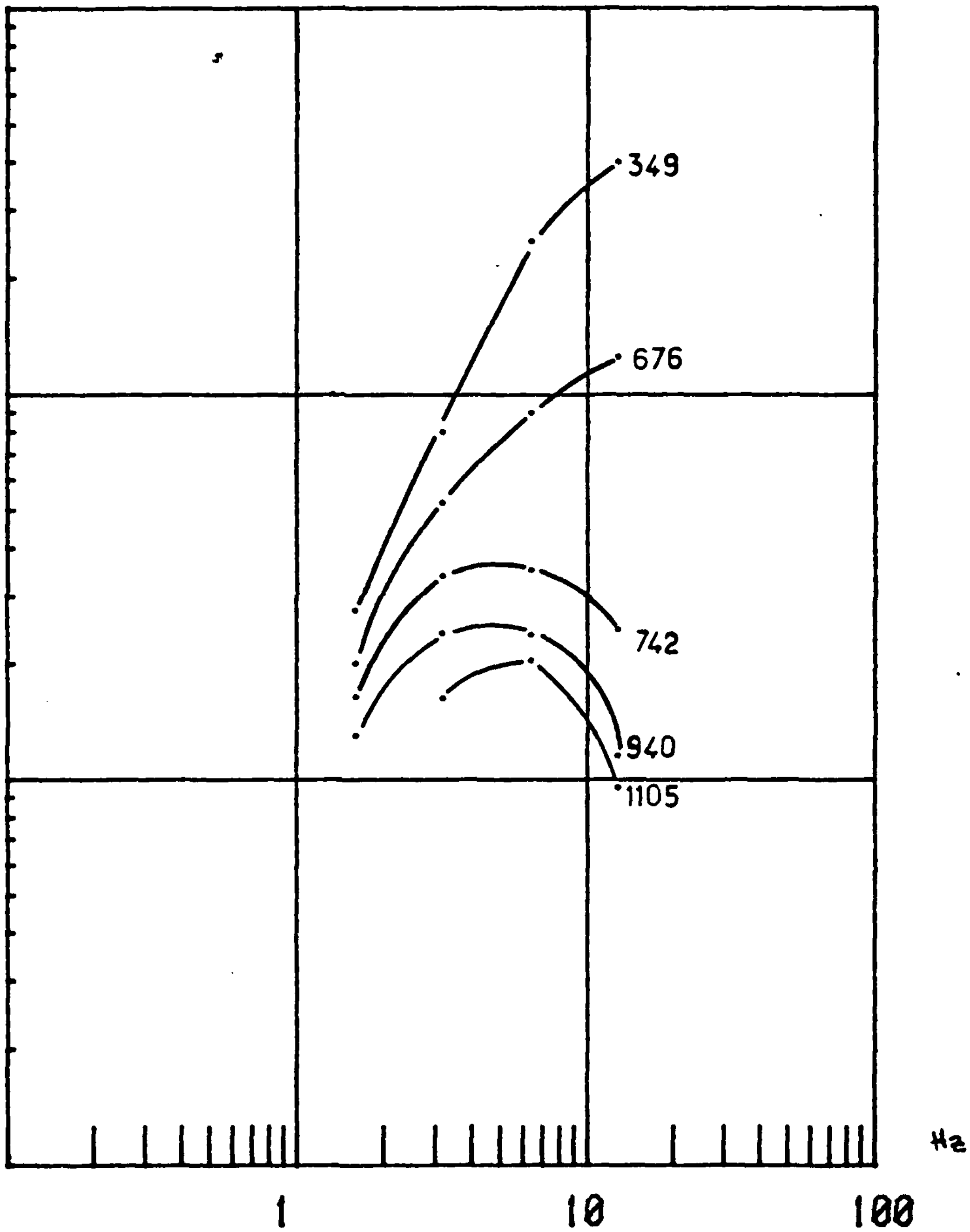
QUAKE 12.ATTENUATION Pn PHASE
FILTERED SIGNAL:4 - 8 Hz

Fig. 10



QUAKE 12.ATTENUATION Pn PHASE
FILTERED SIGNAL:8 - 16 Hz

Fig. 11



SPECTRA OF Pn VERSUS FREQUENCY

Fig. 12

I - Pn PHASE

Pn frequency contain is essentially high frequencies one.
For stations closed to the source ($\Delta \leq$ 400km) maximum amplitudes are obtained on the 8-16Hz band. Beyond this distance of 400km, the maximum amplitudes shift to the 4-8Hz band.
Basically attenuation coefficients γ defined as follows :

$$A \propto KD^{-\gamma}$$

have been computed in each of the 5 frequency bands by measuring maximum amplitudes on filtered data :

Δf	γ	correlation	phases
0. 5 - 1Hz	no consistant data	—	—
1 - 2Hz	0. 40	0. 31	16
2 - 4Hz	1 . 20	0. 77	17
4 - 8Hz	1. 80	0. 81	17
8 -16Hz	2. 70	0. 87	17
original signal	1. 90	0. 87	17

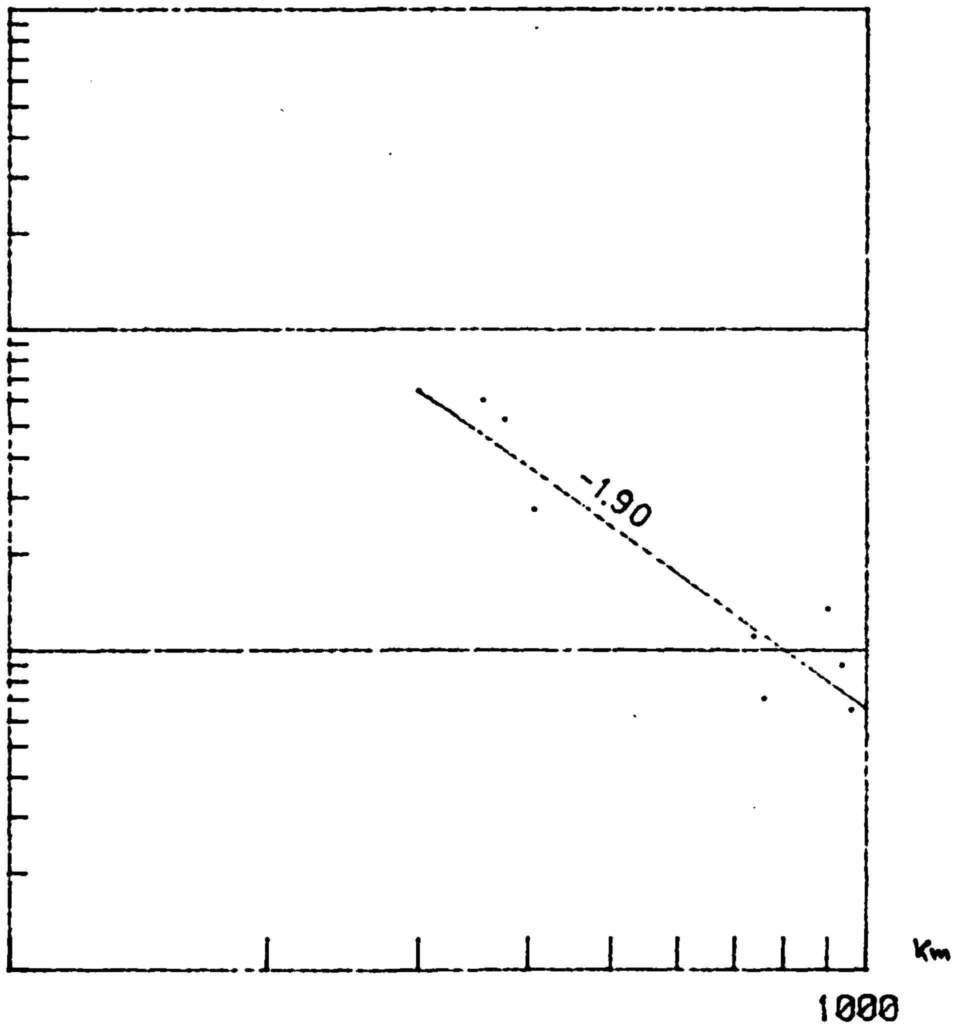
High frequencies (8-16Hz) are more strongly attenuated than low frequencies (1-2Hz) and so the frequency contain is becoming poorer when distance increases.

Nevertheless, in Provence network (LRG, SPF and LMR) at 1100km from the epicenter, no clear low frequency component was seen as we should expect, according to former results on other earthquakes. On the contrary, high frequencies (4-8Hz) were reported.

This remark points out that geological anomalies might affect the main results which are observed. In that particular Provence case, it seems that the "sillon rhodanien", large trench noth-south oriented at west side from Provence could affect the low frequency propagation and might act as a high pass filter.

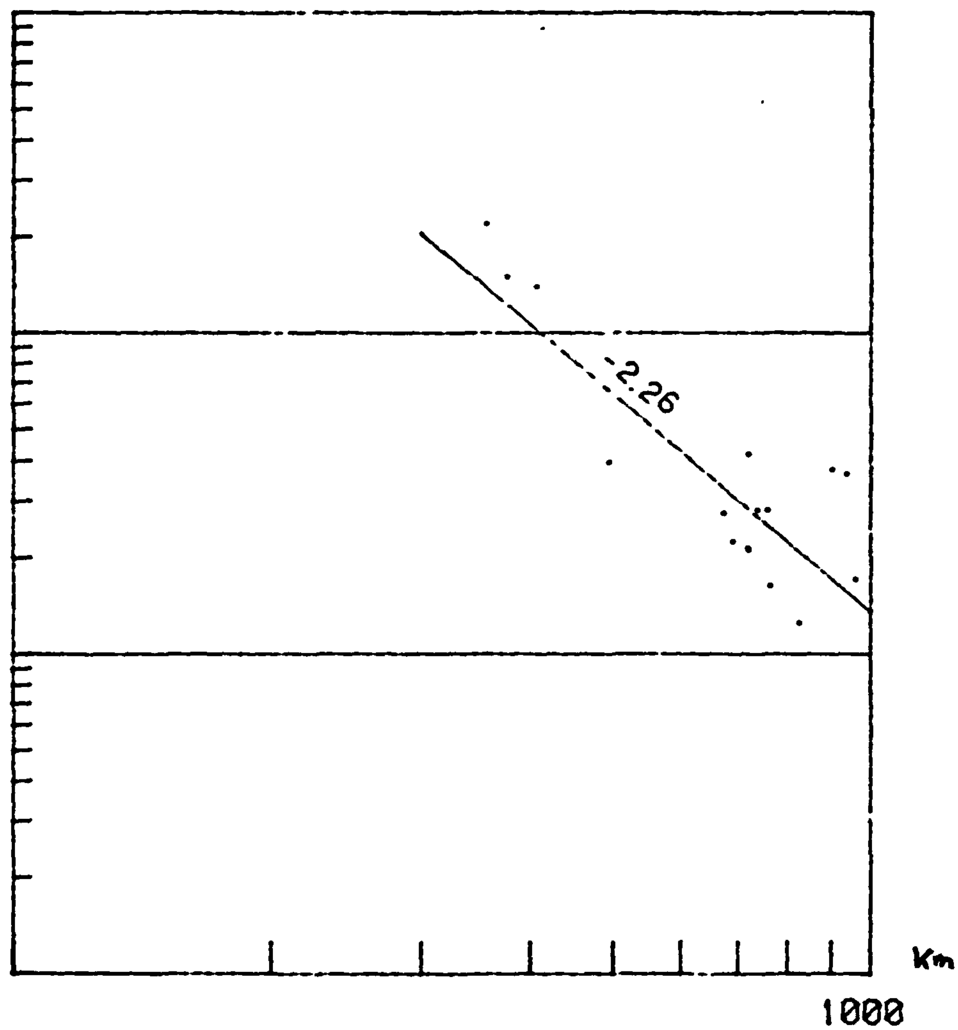
Pg Phase

- Plot of Amplitude versus distance.
- Spectra at various distances.
- Main characteristics.



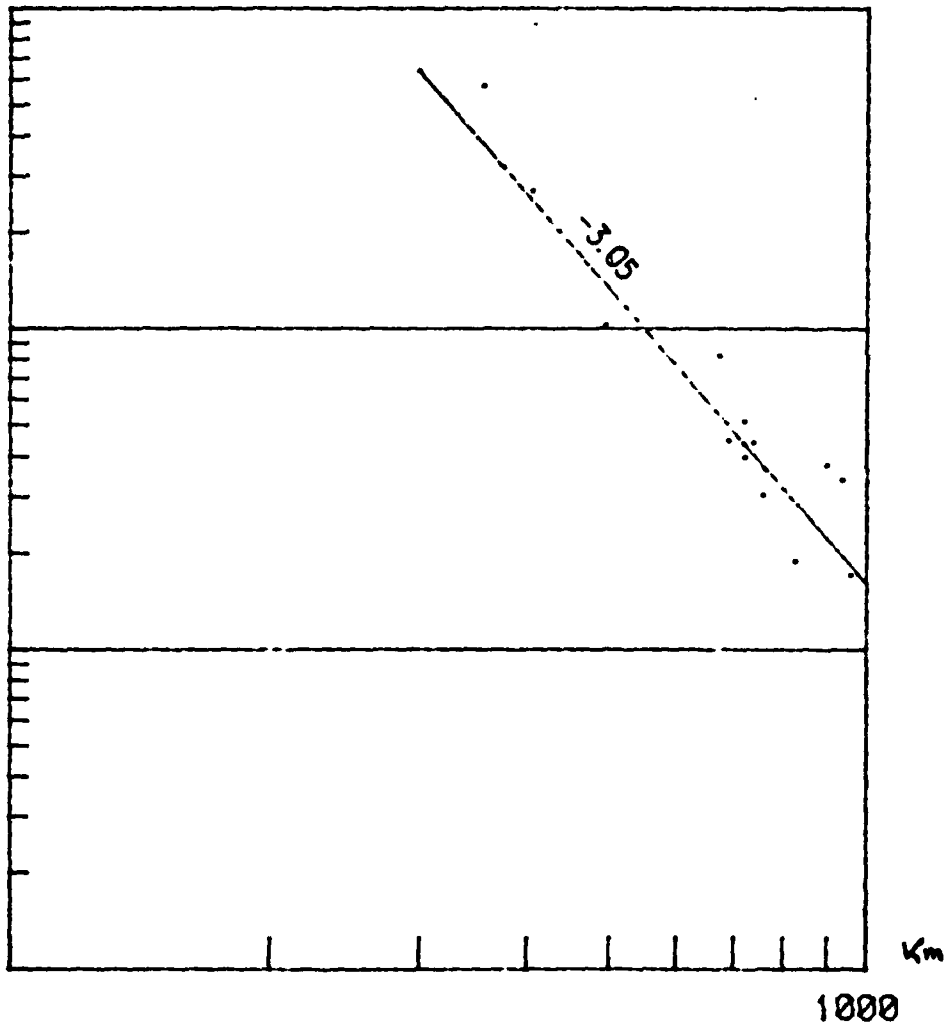
QUAKE 12.ATTENUATION Pg PHASE
FILTERED SIGNAL:0.5 - 1 Hz

Fig. 13



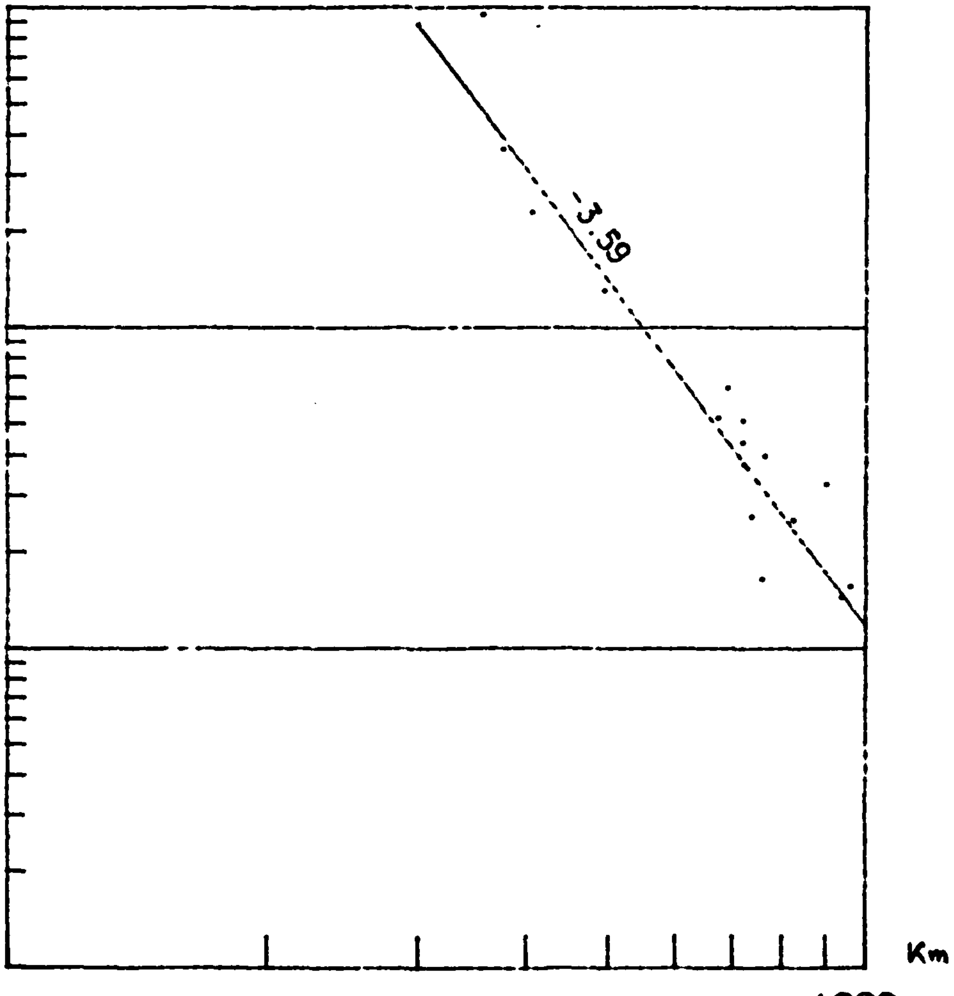
QUAKE 12.ATTENUATION Pg PHASE
FILTERED SIGNAL: 1 - 2 Hz

Fig. 14



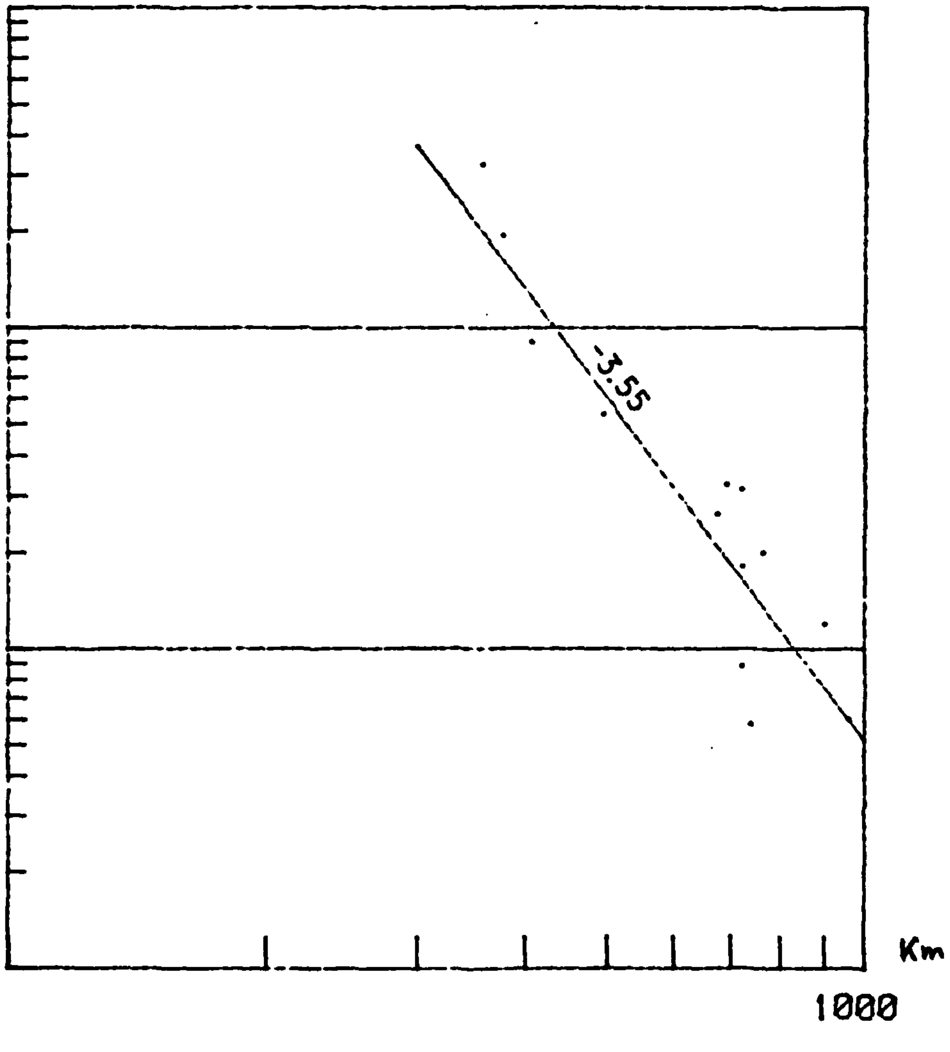
QUAKE 12.ATTENUATION P_g PHASE
FILTERED SIGNAL:2 - 4 Hz

Fig. 15



QUAKE 12.ATTENUATION Pg PHASE
FILTERED SIGNAL:4 - 8 Hz

Fig. 16



QUAKE 12.ATTENUATION Pg PHASE
FILTERED SIGNAL:8 - 16 Hz

Fig. 17

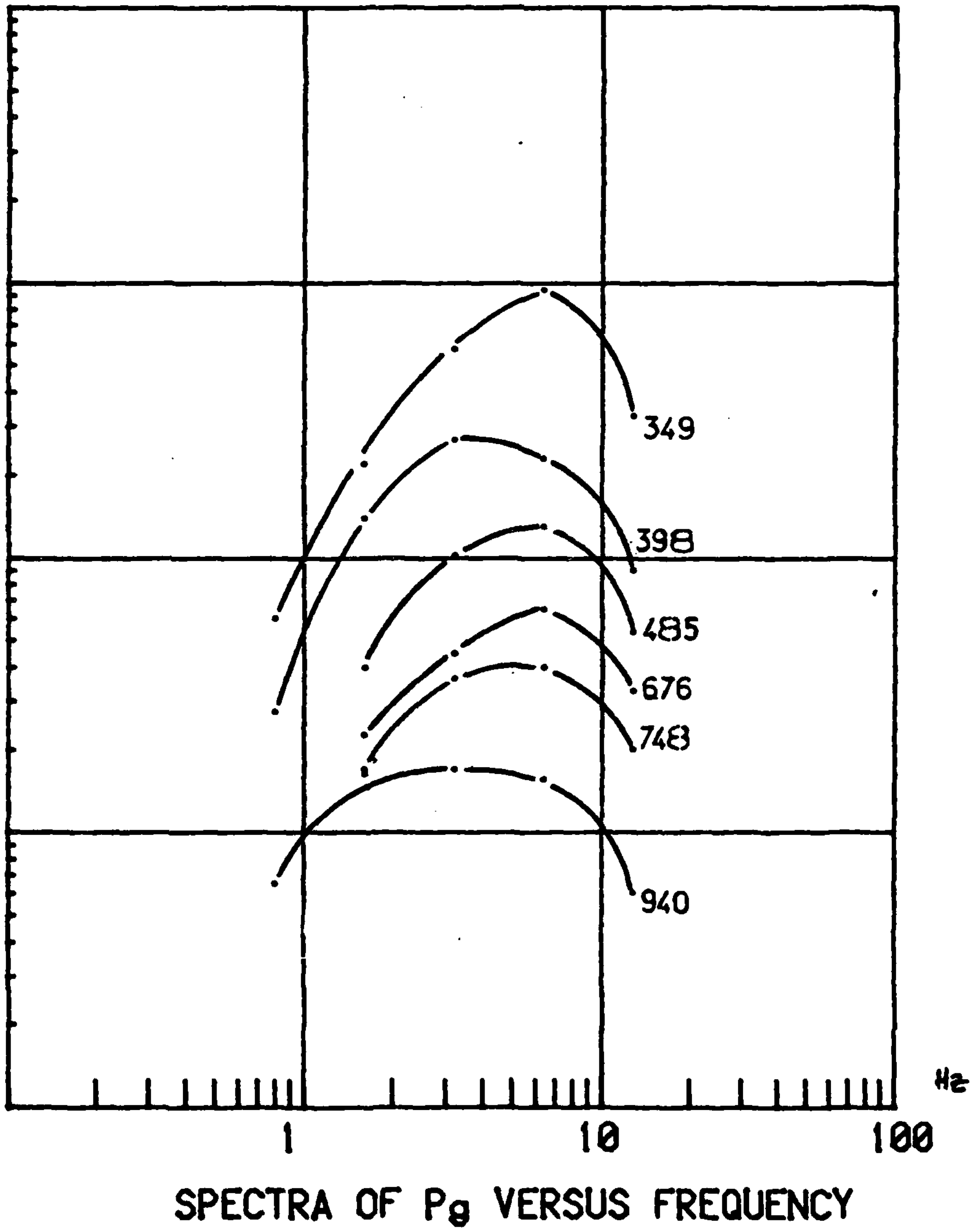

349
398
485
676
748
940
Hz
1
10
100
SPECTRA OF Pg VERSUS FREQUENCY

Fig. 18

II - Pg PHASE

Rather difficult to notice on broad band signals, it appears more clearly on filtered data, with a frequency contain lower than Pn. Again high frequencies are attenuated stronger than low frequencies, and maximum amplitude is in the 4-8Hz for close stations ($\Delta <$ 400km), and shift to 2Hz arond 900km :

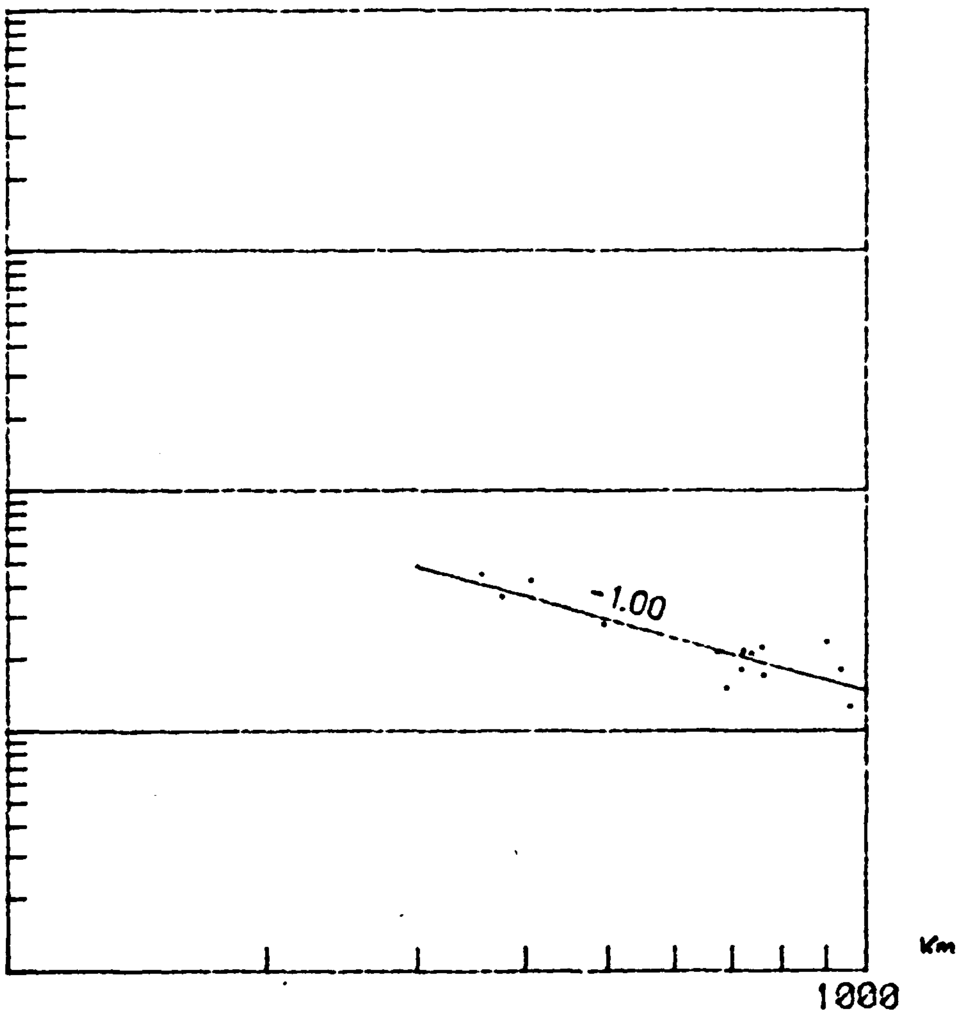
Δf	γ	correlation	phases
0. 5 - 1Hz	1. 9	0. 93	8
1 - 2Hz	2. 3	0. 86	16
2 - 4Hz	3.	0. 96	16
4 - 8Hz	3. 6	0. 96	16
8 -16Hz	3. 5	0. 92	13
original signal	3.	0. 95	17

Provence stations do not record any Pg phase.
On the other hand, one should be particularely careful about the nature of what we use to call a Pg phase : a phase which propagates at 6km/sec.

In this particular case of Britanny quake, which presumed depth is around 25km, it seems rather difficult to confirm the nature of that phase all along the network. Some other earthquakes as n°3 of our previous list (Oleron) might give more consistant informations on the frequency contain of it.

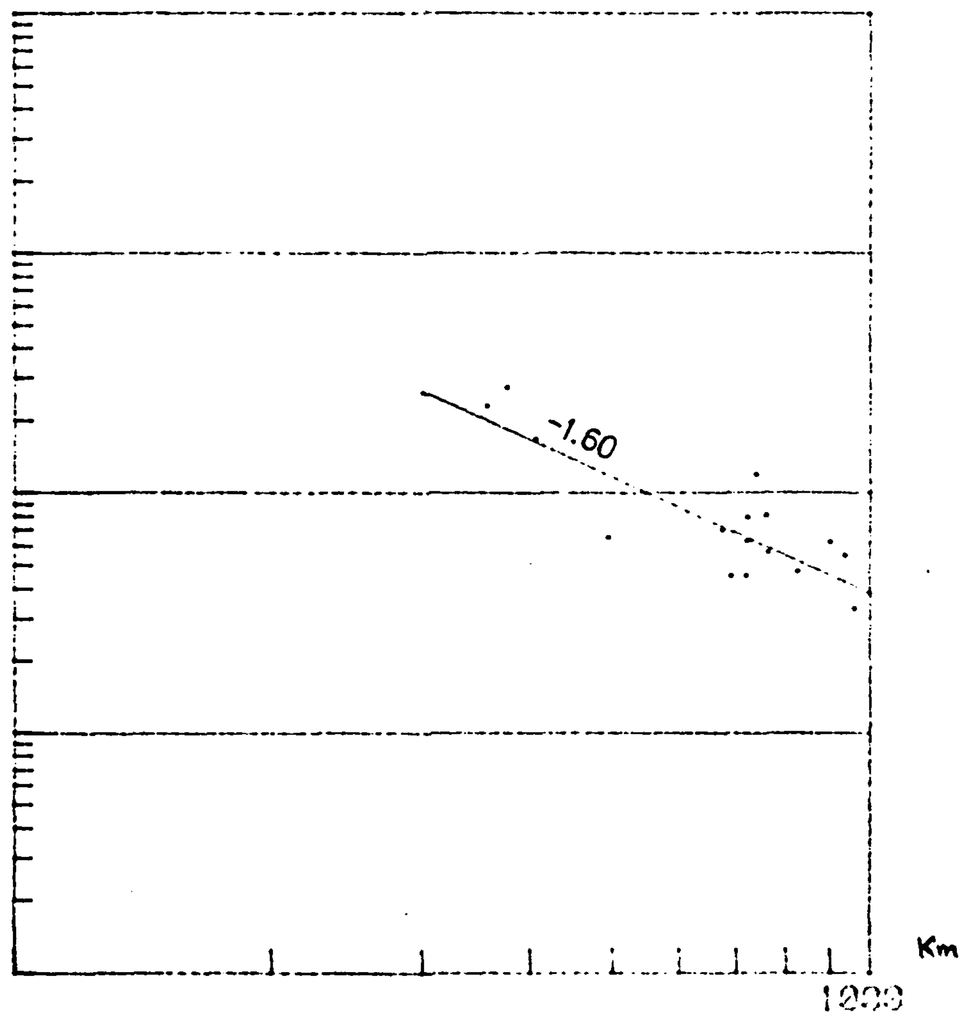
Sn Phase

- Plot of Amplitude versus distance.
- Spectra at various distances.
- Main characteristics.



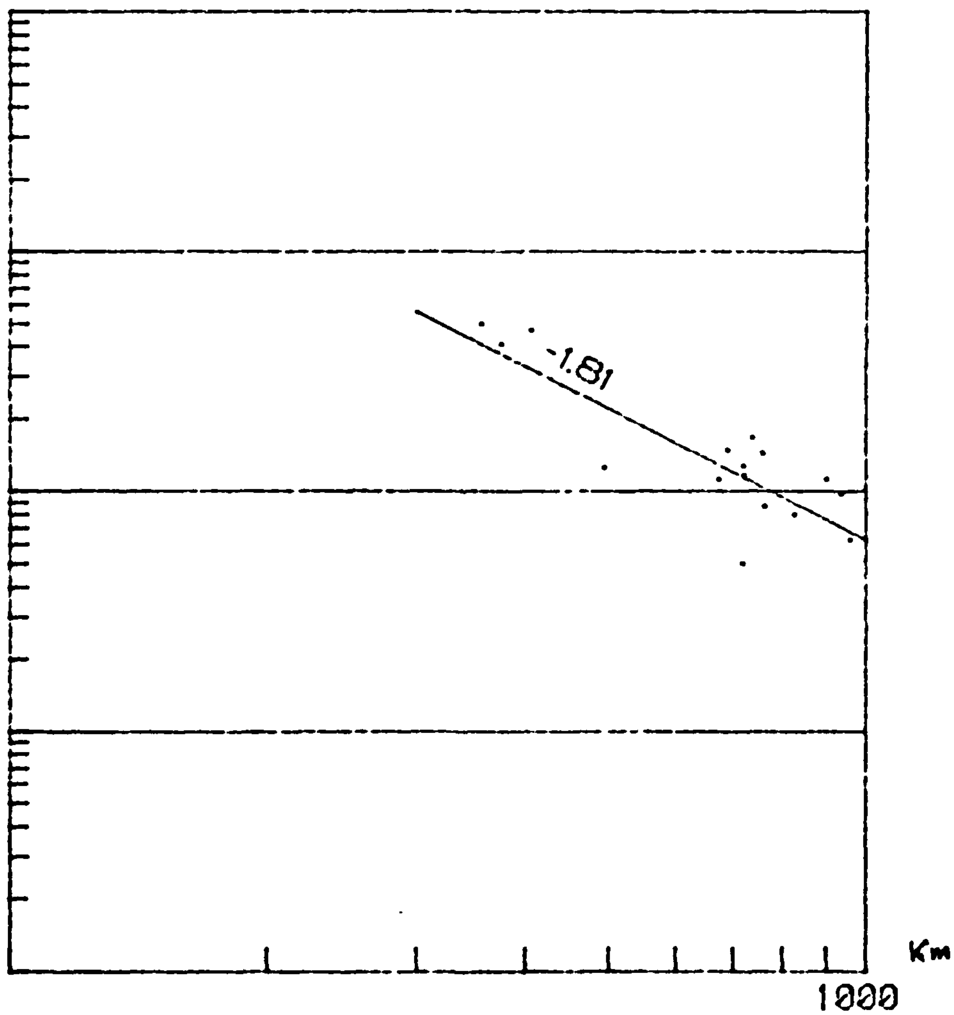
QUAKE 12.ATTENUATION Sn PHASE
FILTERED SIGNAL:0.5 - 1 Hz

Fig. 19



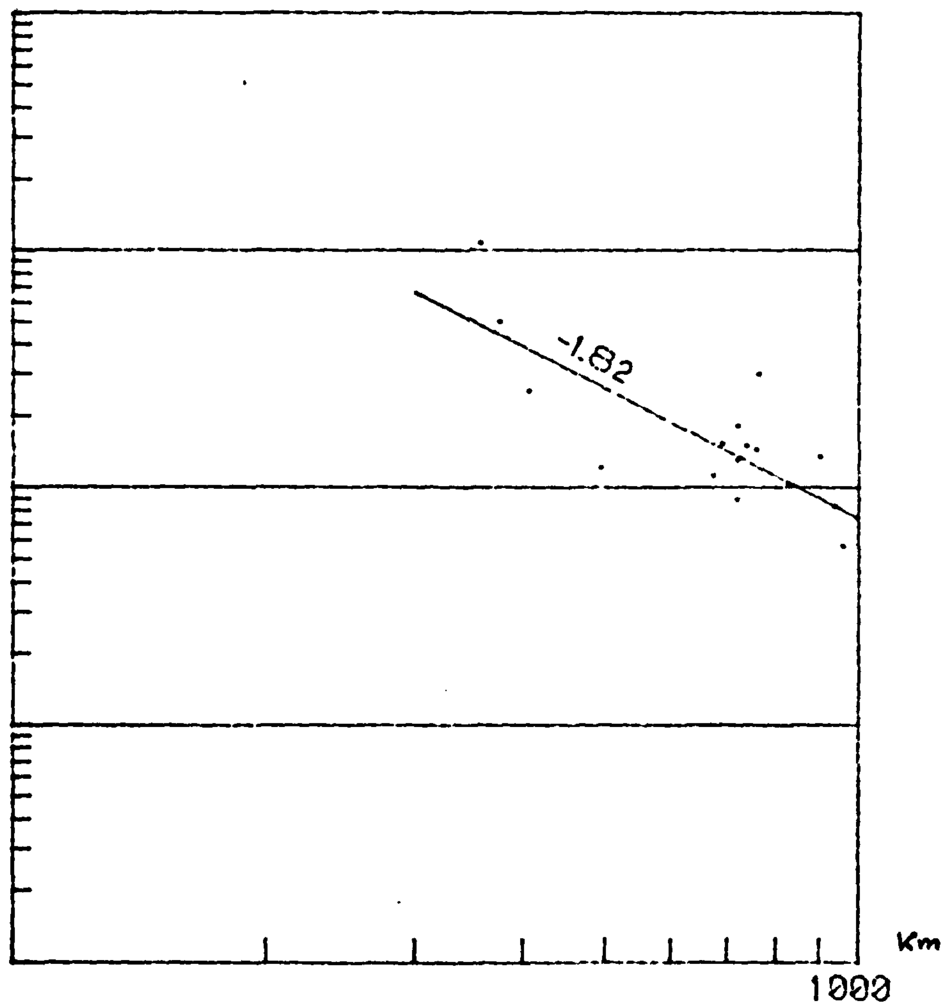
QUAKE 12.ATTENUATION Sn PHASE
FILTERED SIGNAL: 1 - 2 Hz

Fig. 20



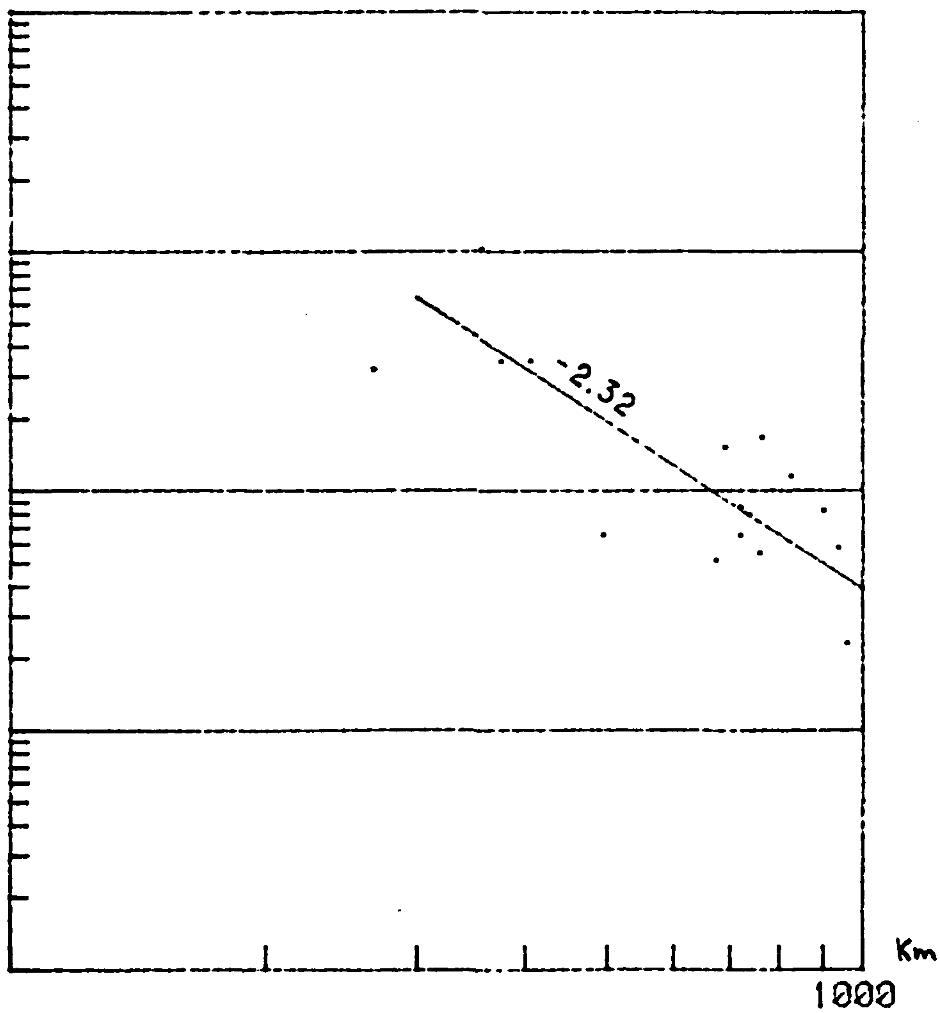
QUAKE 12.ATTENUATION Sn PHASE
FILTERED SIGNAL:2 - 4 Hz

Fig. 21



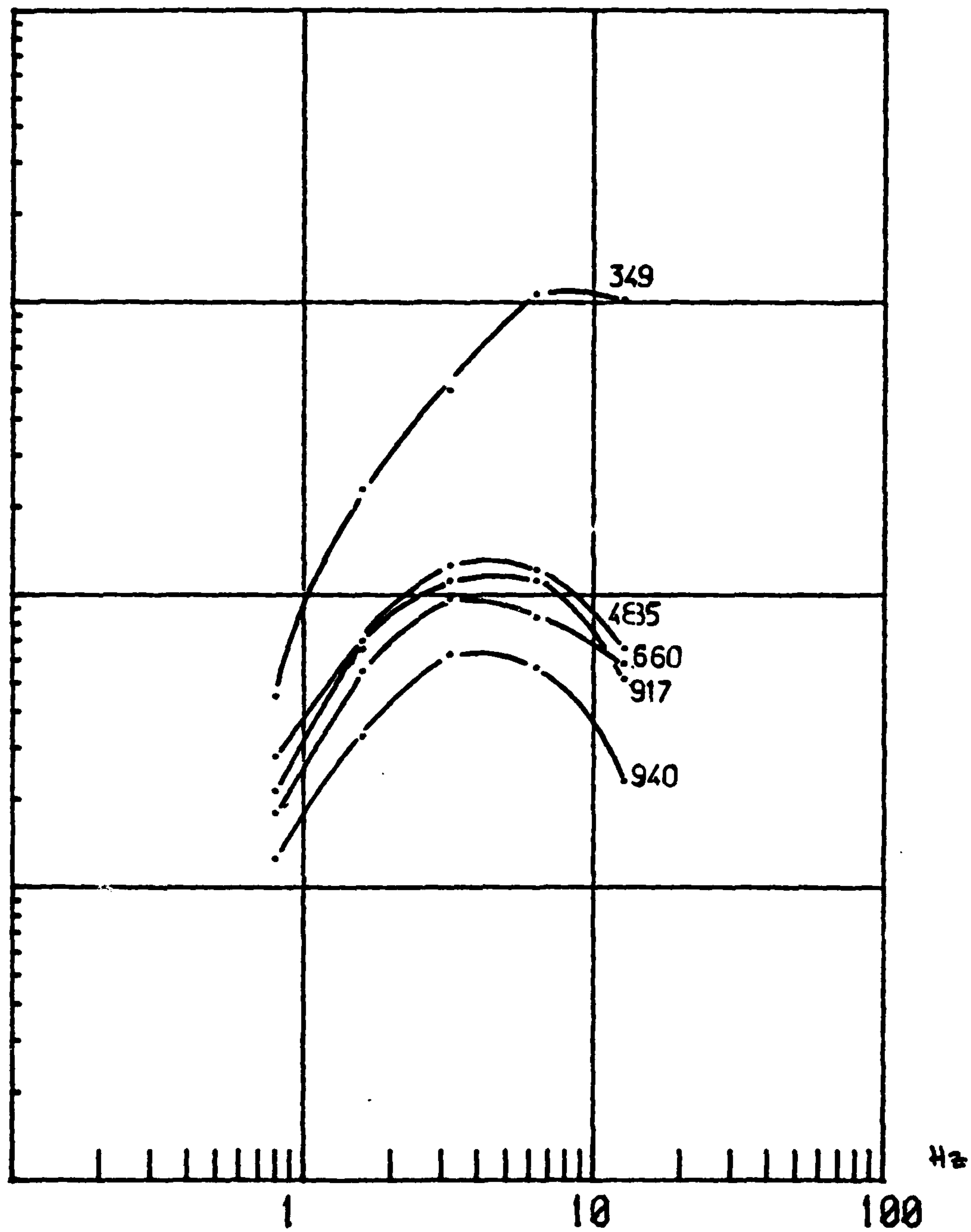
QUAKE 12.ATTENUATION Sn PHASE
FILTERED SIGNAL: 4 - 8 Hz

Fig. 22



QUAKE 12.ATTENUATION Sn PHASE
FILTERED SIGNAL:8 - 16 Hz

Fig. 23



SPECTRA OF Sn VERSUS FREQUENCY

Fig. 24

III - Sn PHASE

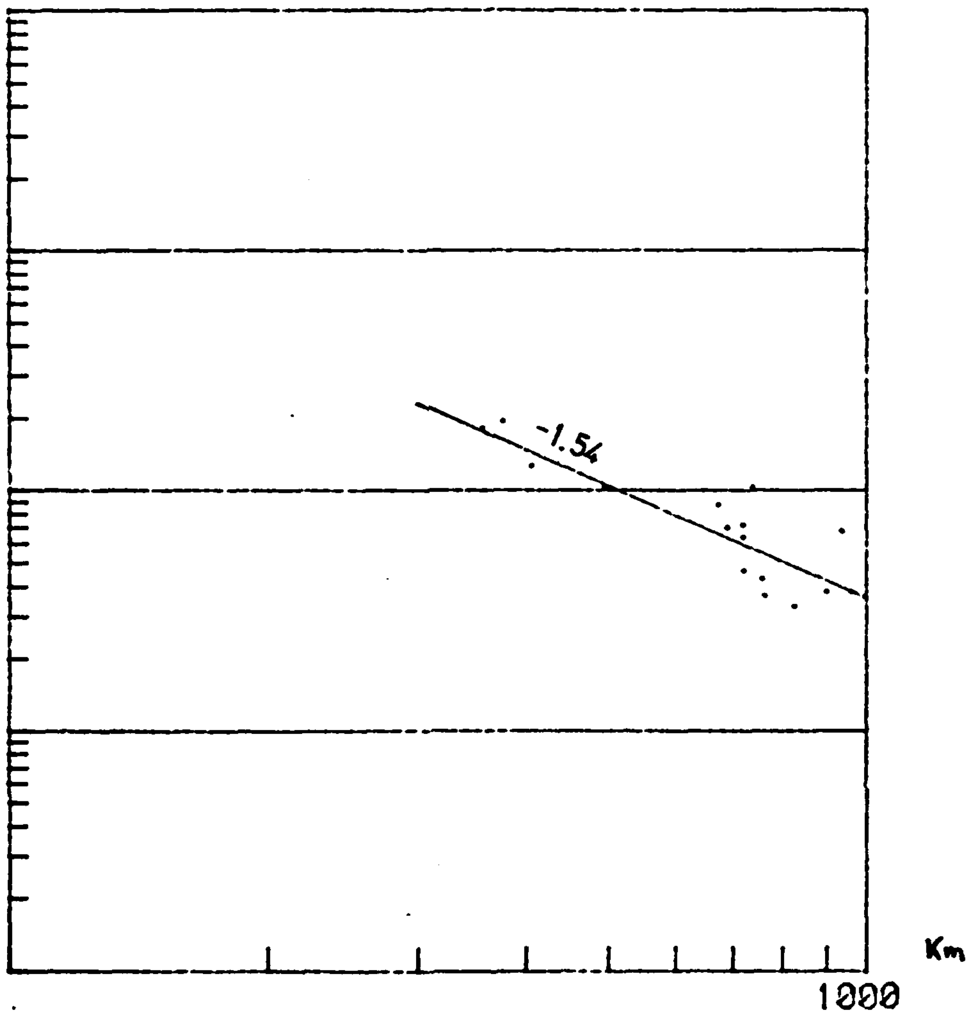
Having the most extendable frequency contain, this phase propagates in the first hundreds of km with a maximum energy around 8Hz, shifting down to 2Hz at distant stations (Vosges). Its frequency band is situated in between Pn and Pg frequency bands.

Δf	γ	correlation	phases
0.5 - 1Hz	1.	0.88	15
1 - 2Hz	1.6	0.84	16
2 - 4Hz	1.8	0.85	16
4 - 8Hz	1.8	0.79	16
8 -16Hz	2.3	0.8	16
Broad band signal	2.1	0.85	17

Attenuation coefficient γ versus distance decreases from + 2.3 at 8 - 16Hz down to + 1 at 0.5 - 1Hz, with, as for Pn phase, a rather scatter (see correlation coefficient).

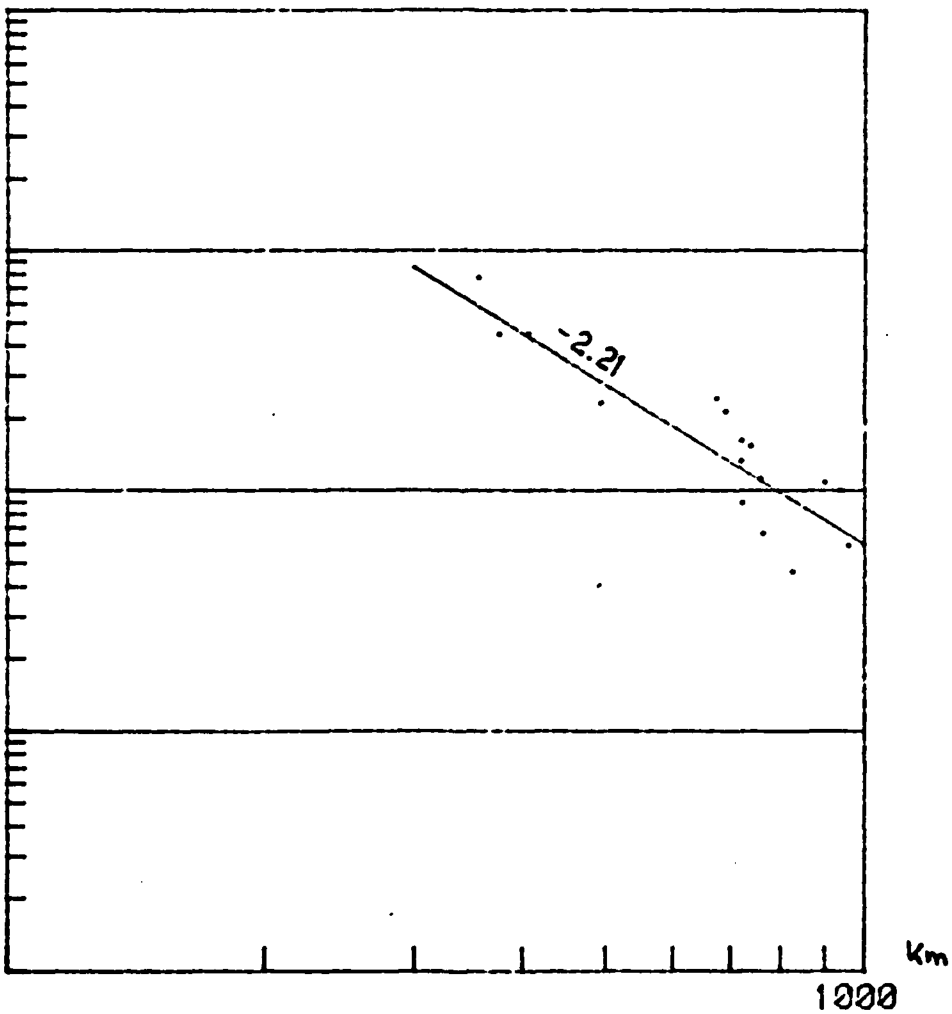
Lg Phase

- Plot of Amplitude versus distance.
- Spectra at various distances.
- Main characteristics.



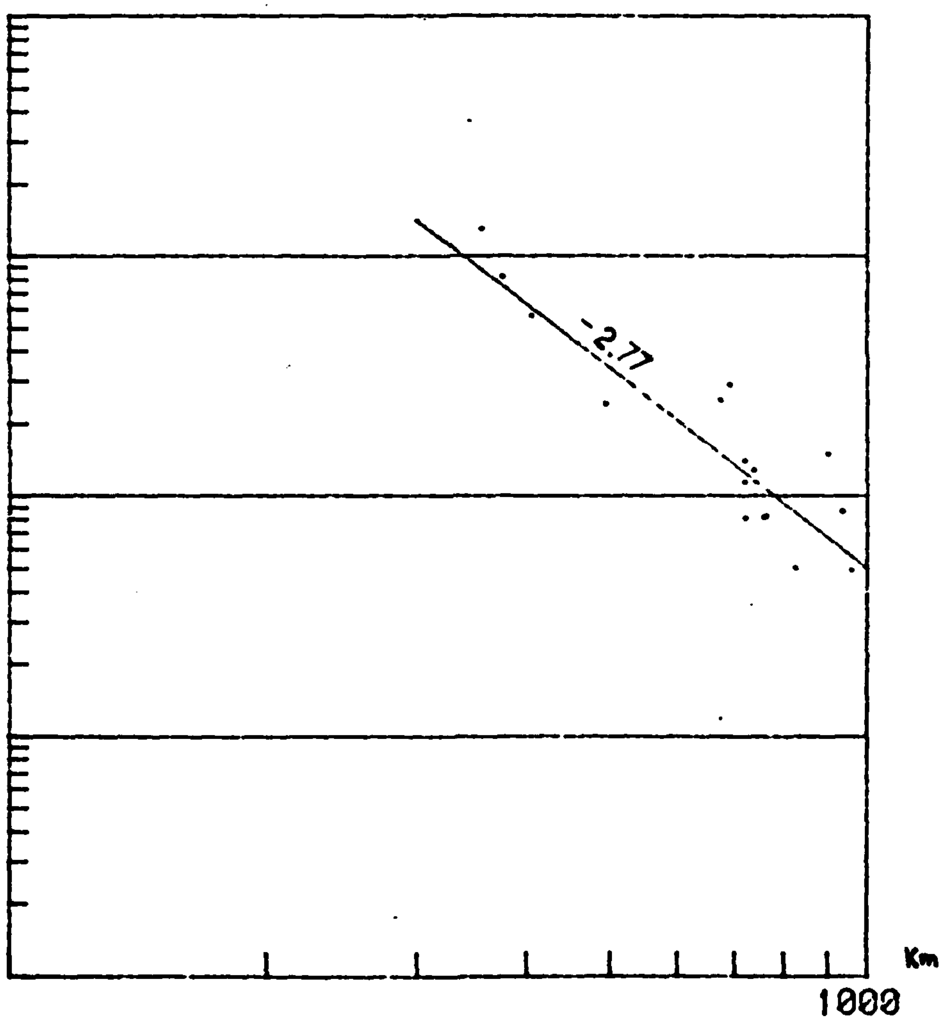
QUAKE 12.ATTENUATION Lg PHASE
FILTERED SIGNAL:0.5 - 1 Hz

Fig. 25



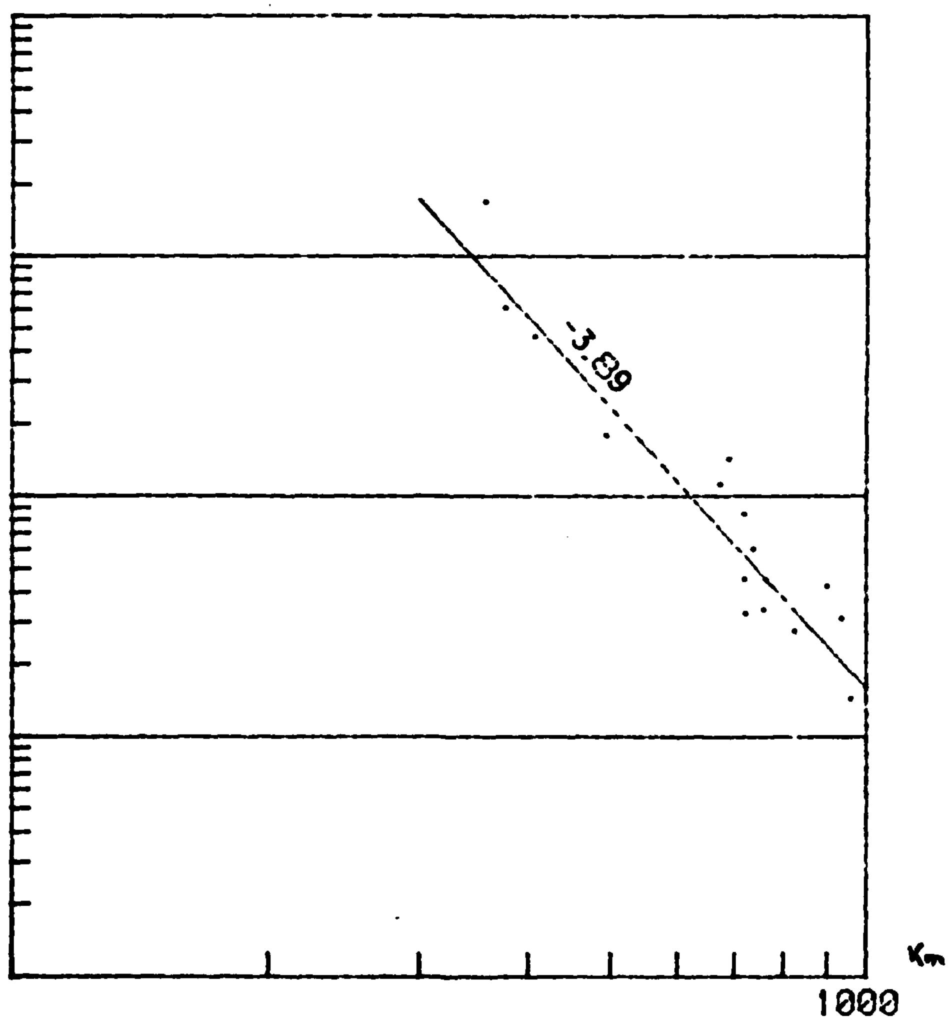
QUAKE 12. ATTENUATION Lg PHASE
FILTERED SIGNAL: 1 - 2 Hz

Fig. 26



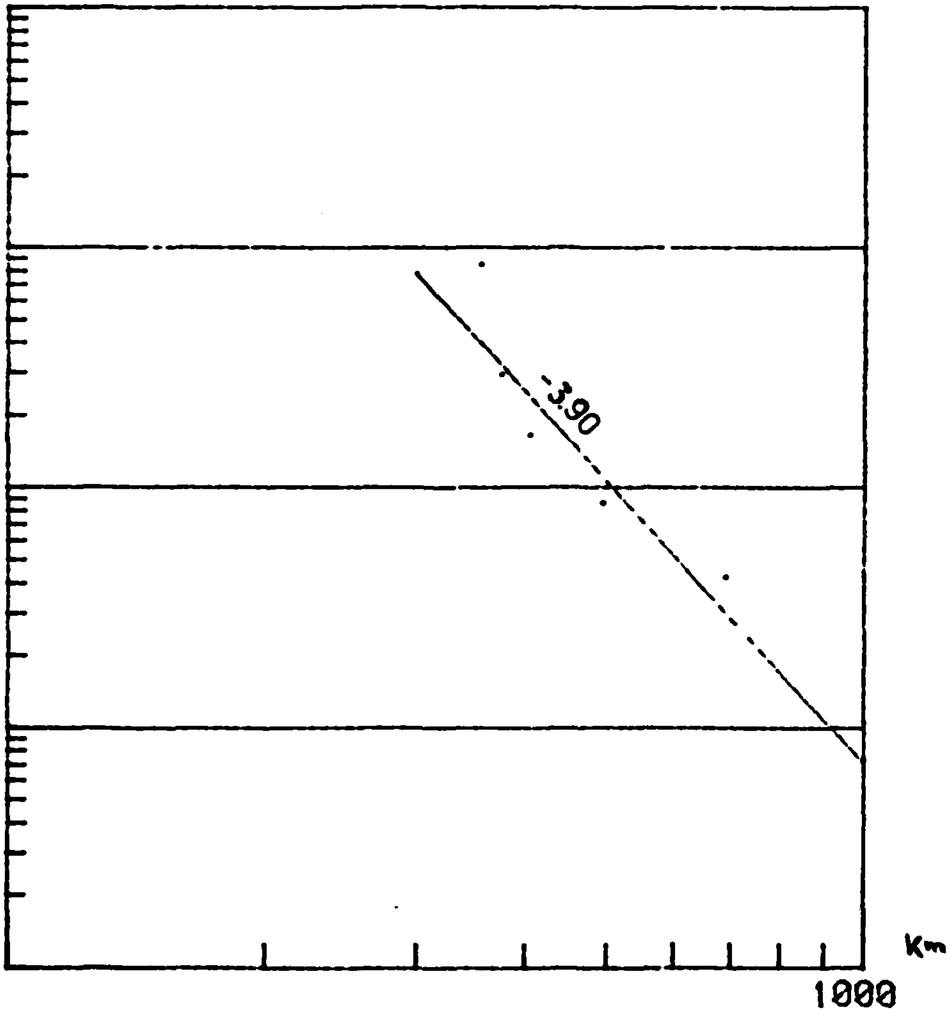
QUAKE 12.ATTENUATION Lg PHASE
FILTERED SIGNAL:2 - 4 Hz

Fig. 27



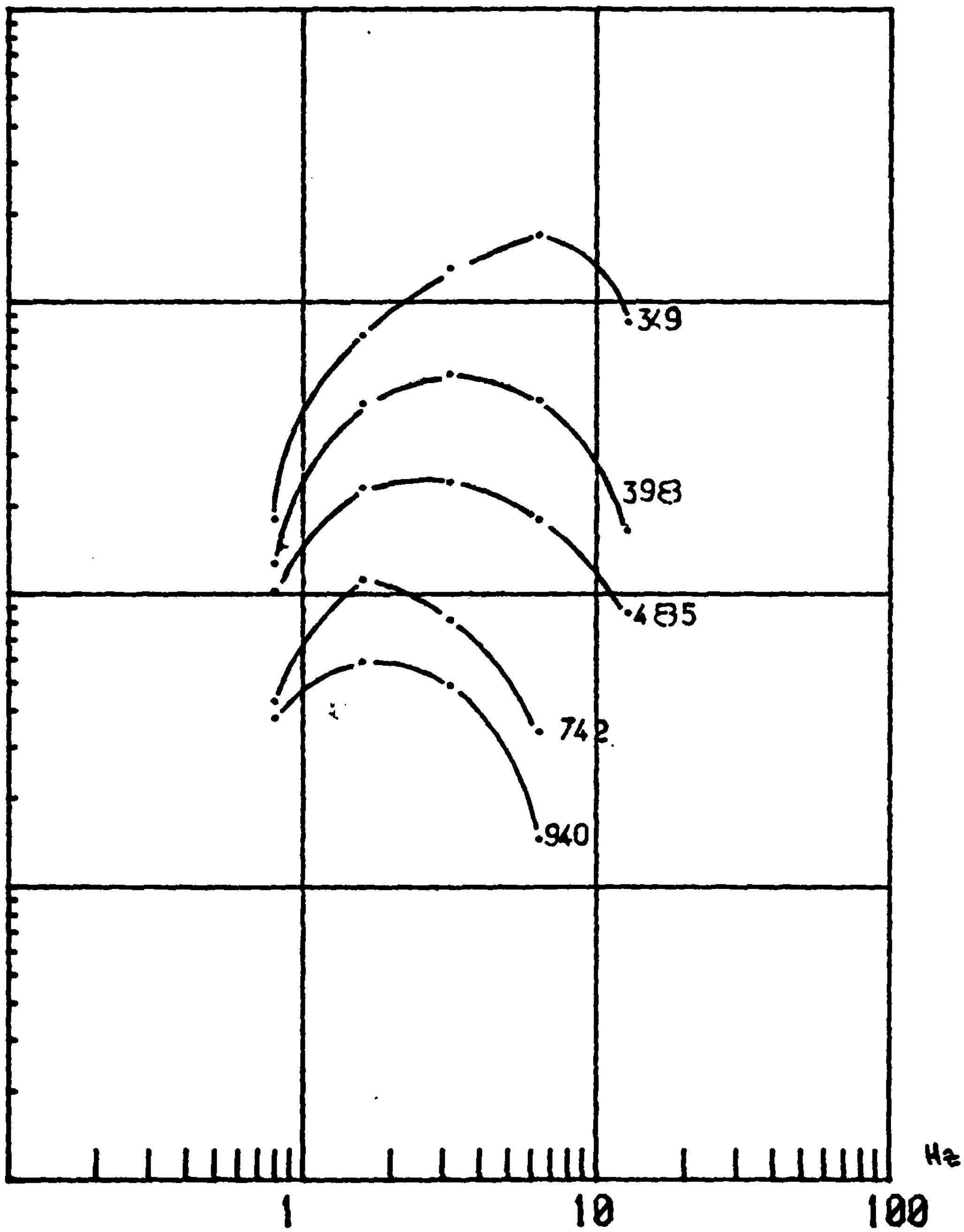
QUAKE 12.ATTENUATION Lg PHASE
FILTERED SIGNAL:4 - 8 Hz

Fig. 28



QUAKE 12.ATTENUATION Lg PHASE
FILTERED SIGNAL:8 - 16 Hz

Fig. 29



SPECTRA OF Lg VERSUS FREQUENCY

Fig. 30

IV - Lg PHASE

Characteristed by a low frequency spectrum in comparison to the last phase, Lg maximum energy is found in the 0. 5 -4Hz frequency band except for very short distances. Frequencies of 8Hz and more are reported only for distances $\Delta <$ 600km.

Group velocity dispersion from high to low frequencies (high frequencies travelling faster than low frequencies) is to be pointed out.

Again, no Lg confirm that low frequencies are affected along their propagation to Provence and this could be due to "sillon rhodanien" area.

Attenuation coefficients decrease also from 3. 9 at (8 - 16Hz) down to 1. 5 at (0. 5 - 1Hz).

Δf	γ	correlation	phases
0. 5 - 1Hz	1. 5	0. 86	16
1 - 2Hz	2. 2	0. 89	16
2 - 4Hz	2. 8	0. 91	16
4 - 8Hz	3. 9	0. 95	16
8 - 16Hz	3. 9	0. 91	5
Broad band signal	2. 6	0. 91	17

PART IV

VARIATION OF ATTENUATION FACTORS VERSUS FREQUENCY VALUES OF QUALITY FACTORS

Attenuation factors.

From the table of attenuation factors, it is obvious that, for all phases, higher the frequency, stronger is the attenuation.

The variation versus frequency of the attenuations factors could be expressed as

$$\gamma = - c f^{\alpha}$$

or

$$\log |\gamma| = \alpha \log f + \log c$$

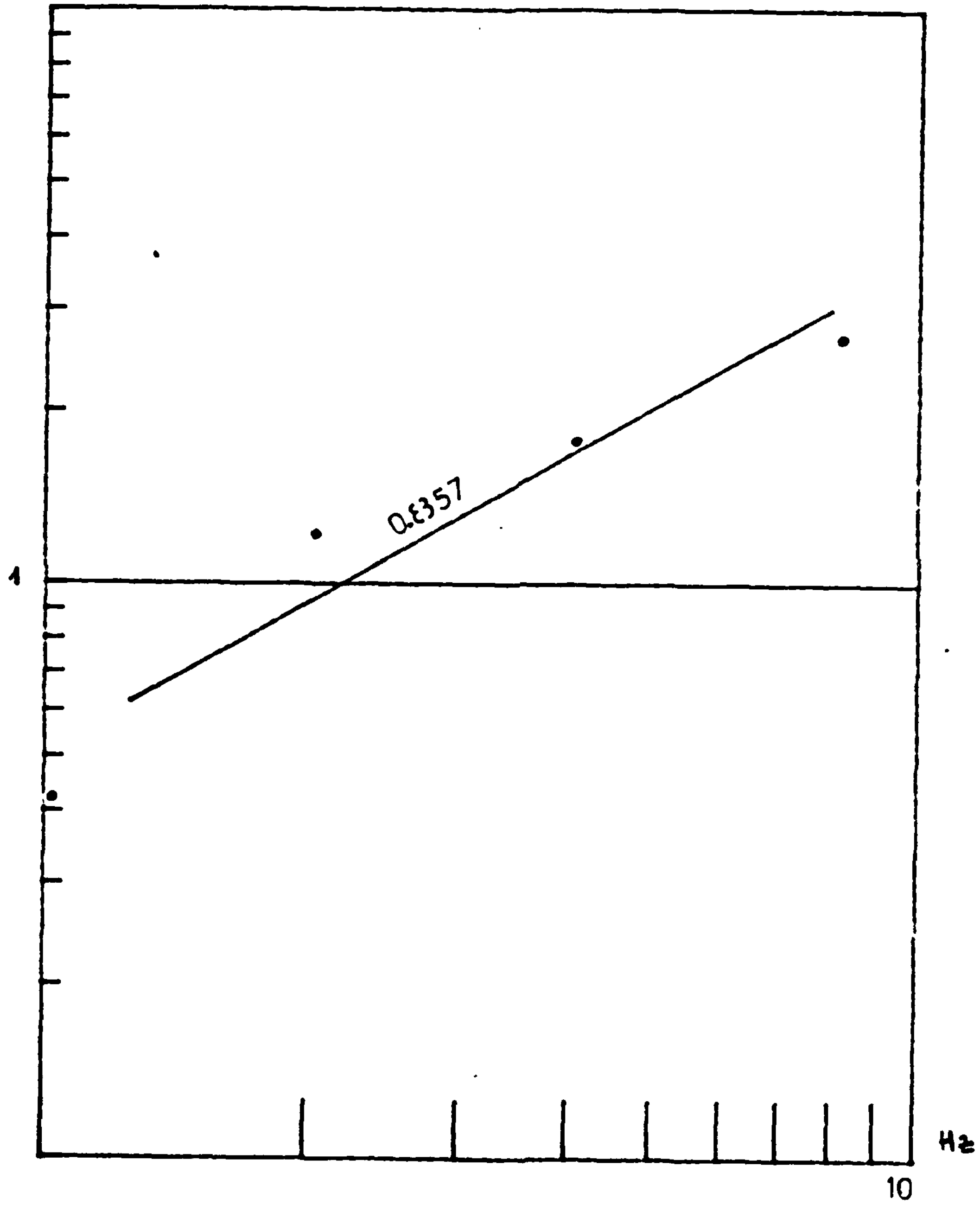
with following results

phase	Pn	Pg	Sn	Lg
α	0. 857	0. 247	0. 261	0. 349
log C	-0. 291	0. 370	0. 138	0. 328
correlation coefficient	0. 96	0. 96	0. 92	0. 97

The 4 correlation coefficients are close from 1, it means that $\log |\gamma|$ is well represented by a linear fonction of $\log f$.

This is clearly seen on the next plot of $\log |\gamma|$ versus $\log f$.

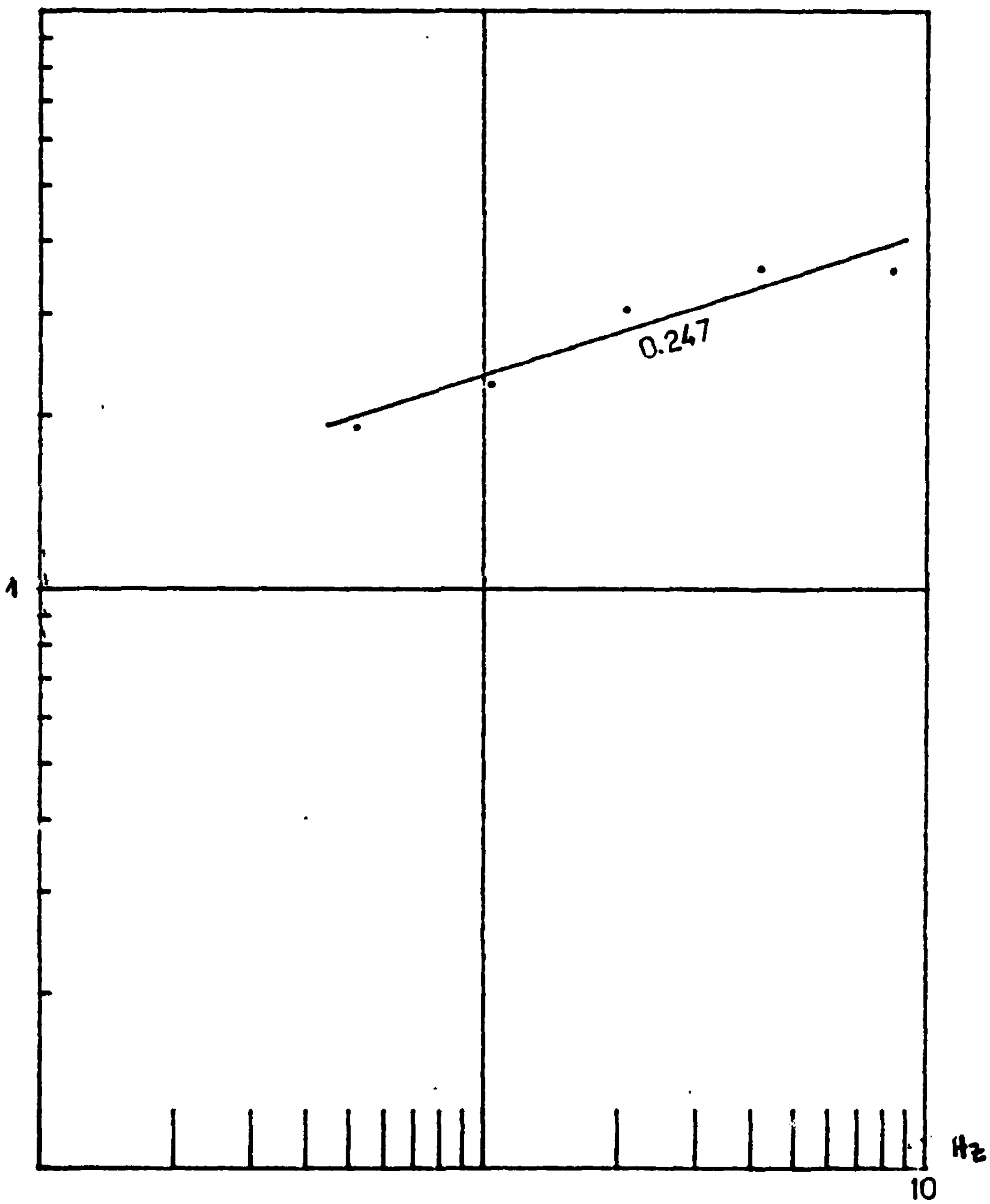
We still have not enough results to give a more accurate description.



QUAKE 12-ATTENUATION VERSUS FREQUENCY

Pn PHASE

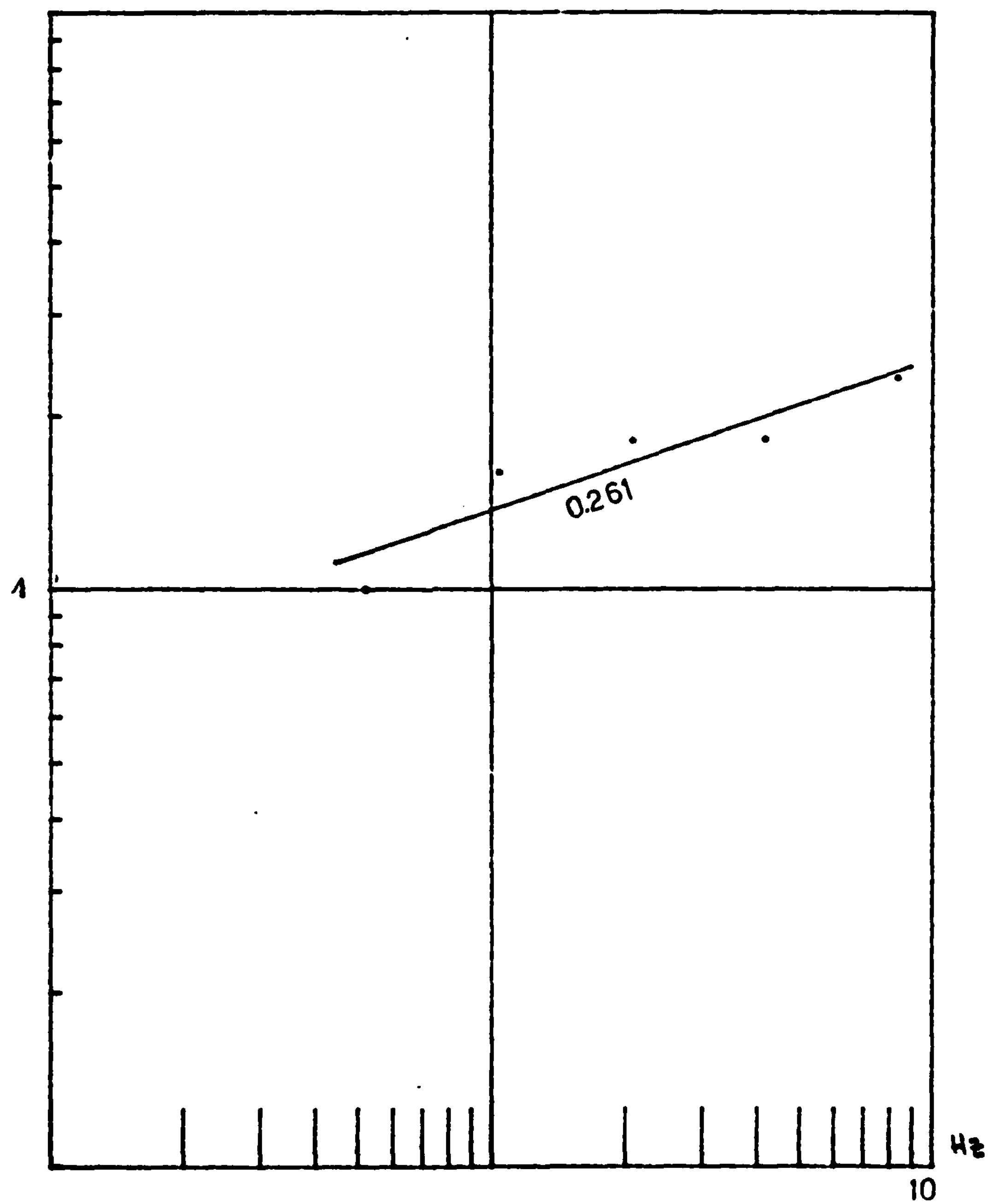
Fig. 31



QUAKE 12-ATTENUATION VERSUS FREQUENCY

Pg PHASE

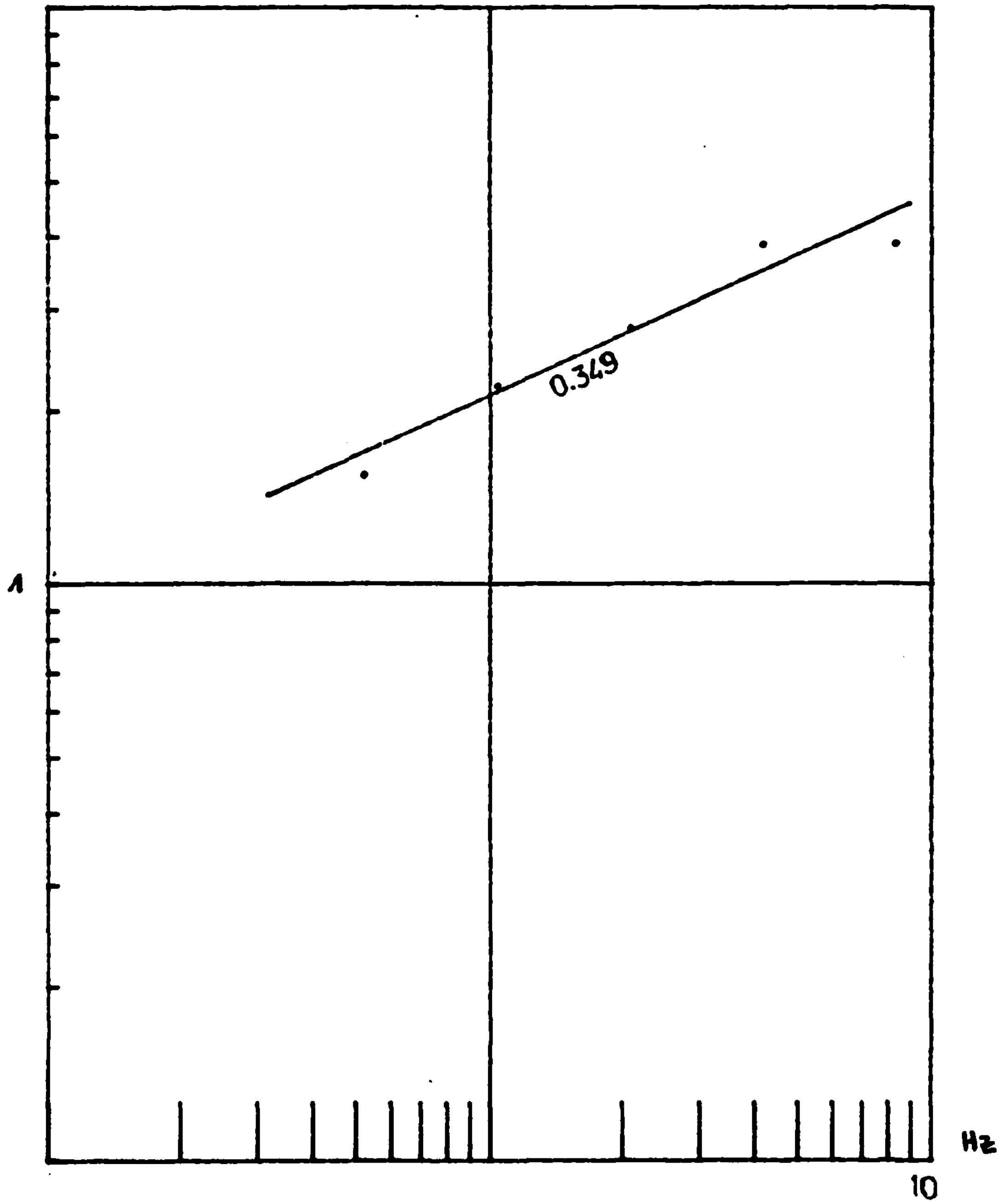
Fig. 32



QUAKE 12-ATTENUATION VERSUS FREQUENCY

Sn PHASE

Fig. 33



QUAKE 12-ATTENUATION VERSUS FREQUENCY

Lg PHASE

Fig. 34

Quality factor Q

In all previous parts, we computed one attenuation factor γ related to amplitude and distance through :

$$A = Ao \quad D^{\gamma}$$

It is also very common to introduce a quality factor Q through :

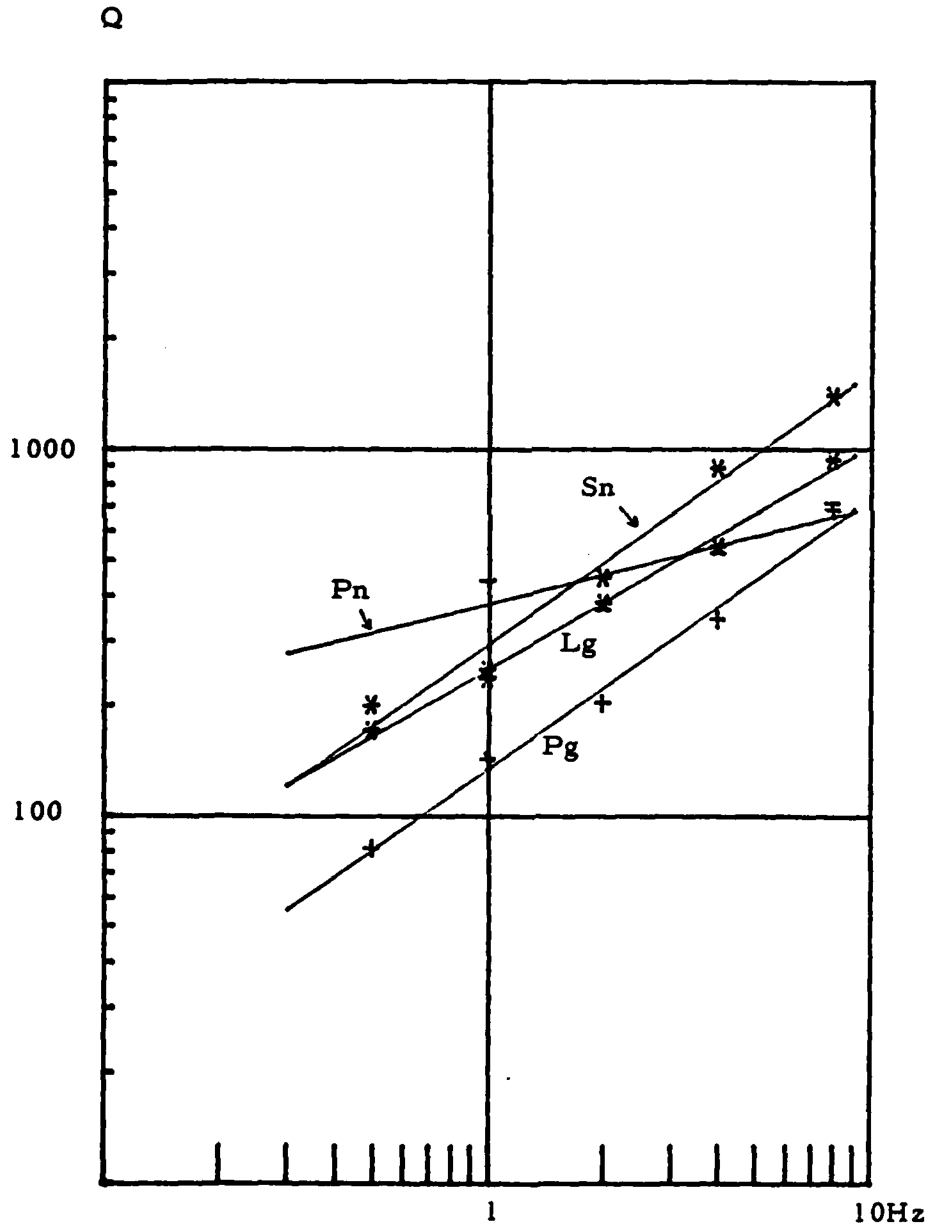
$$A = Ao \quad e^{-\frac{\pi}{Q} f r}$$

Using our data, we computed Q for each phase and each frequency band (in the formula, we used for frequency the lowest cut-off frequency. Each band beeing of 1 octave, an other choice should give similar results).

Phase / Frequency	Pn		Pg		Sn		Lg	
	Stations number	Q	Stations number	Q	Stations number	Q	Stations number	Q
0. 5			8	83	15	204	16	174
1	16	445	16	145	16	256	16	241
2	17	370	16	207	16	454	16	388
4	17	530	16	350	16	900	16	551
8	17	726	13	693	16	1418	5	948

The variation of Q versus frequency and the one of γ versus frequency present a similar feature : an increase with frequency. (Fig. 35)

We do not have enough values to give a definitive conclusion but this pheno - menon will be carefully studied in the next months.



QUAKE 12-Q.FACTOR VERSUS FREQUENCY

Fig. 35

PART V

CONCLUSION

Conclusion.

In order to summarize these first results on frequency contain :

- each phase has a rather different f contain, Pn and Sn are higher frequencies than Pg and principally Lg. These are of course well known general résults.

- high frequencies attenuate far more severely than low frequencies for each of the 4 waves studied here. And for one frequency, attenuation is different for one phase to another.

For example	: at	Δf	= 2 - 4Hz
Pn phase		γ	= + 1. 2
Pg "			= 3. 0
Sn "			= 1. 8
Lg "			= 2. 8

As a result, Pg and Lg phases which frequency contain is rather low versus Pn and Sn, have a more severe attenuation than those last phases.

- Although it is too early to interprete the influence of propagation path on frequency contain, specially on our earthquake, it seems that " sillon rhodanien " area acts as a high pass filter with a frequency cut off around 3Hz : . Provence Stations do not record any low frequency data (and just a few weak high frequency data) as it could be expected on a comparison with Vosges Stations (Δ = 1000km) which has Pg and Sn phases (1 - 2Hz) and Lg phase (1Hz).

- The analog filtered process used here leads to positive results even though rough results on frequencies attenuation. The next step is going to use digital filtering process and get more accuracy, flexibility and speed. Measurements on Q for both Pg, Pn, Sn and Lg will be investigated as will.

- Mean attenuation factor $\bar{\gamma}$ on Lg has been extensively study either for USSR, or USA (West and East parts).

It turns out that for USSR , general features give an attenuation of arount $\bar{\gamma}$ = + 2 , as for Eastern, on the contrary $\bar{\gamma}$ = 4 for western US. (Nersesov, Pomeroy, Blandford). These results correspond to data around 1000km and more.

On the basis of our results over France, it appears that a γ # 2 fits. rather well attenuation from 500 to 1000 km and could be compared to USSR and Eastern USA.